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Improvements to High-Speed Monitoring of Events in Extreme Environments Using Fiber-optic Bragg Sensors

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Disclaimer

Improvements to high-speed monitoring of events in extreme environments using FBG sensors

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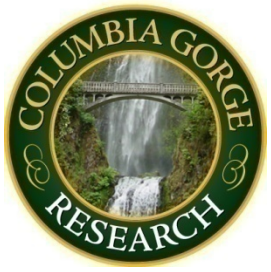

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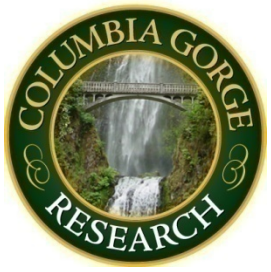
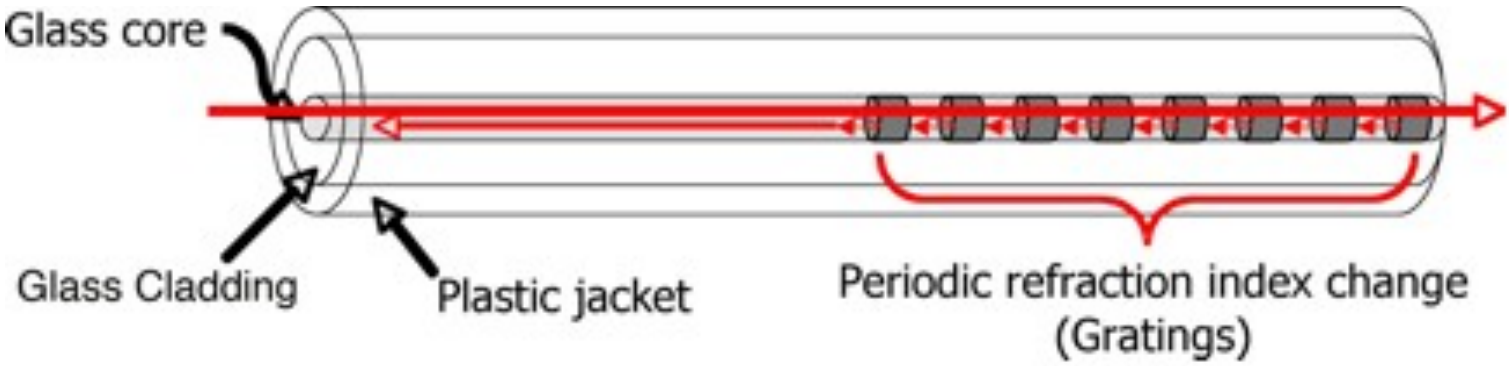
Outline

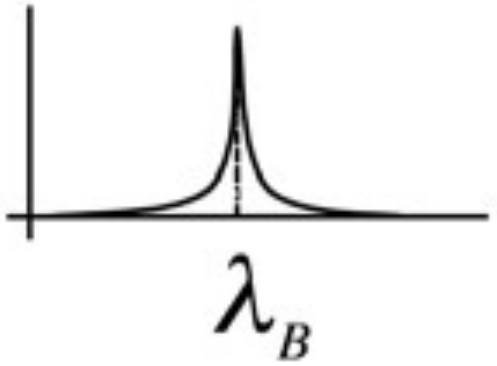
- Background
- First time demonstration of high speed pressure, velocity and position of during burn, deflagration and detonation
- System demonstrations



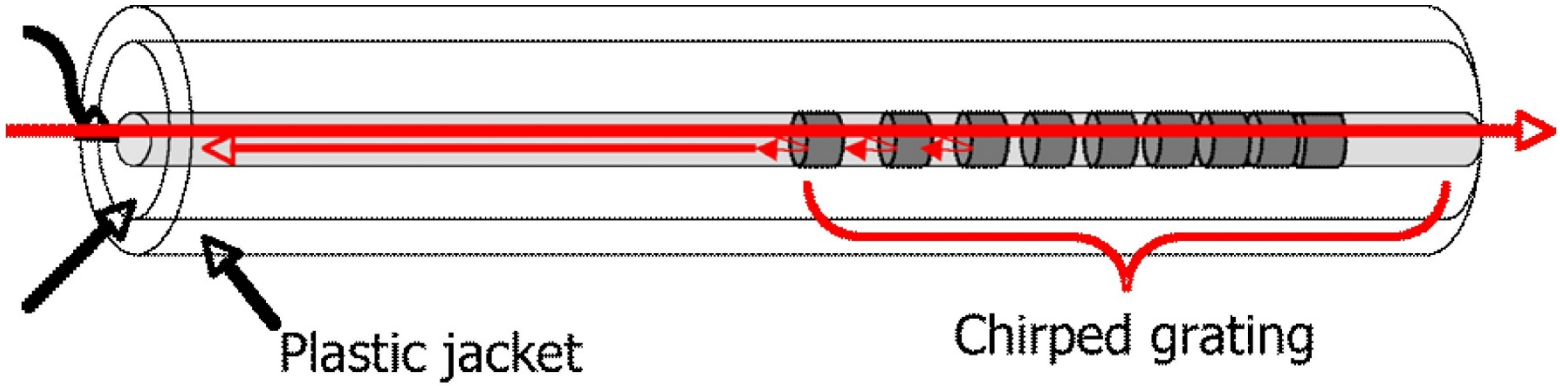
Uniform Fiber Bragg Grating



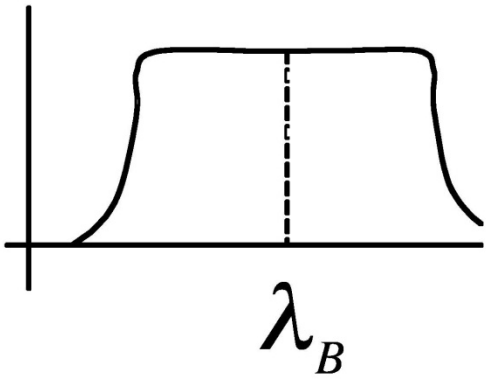
Narrow band reflection



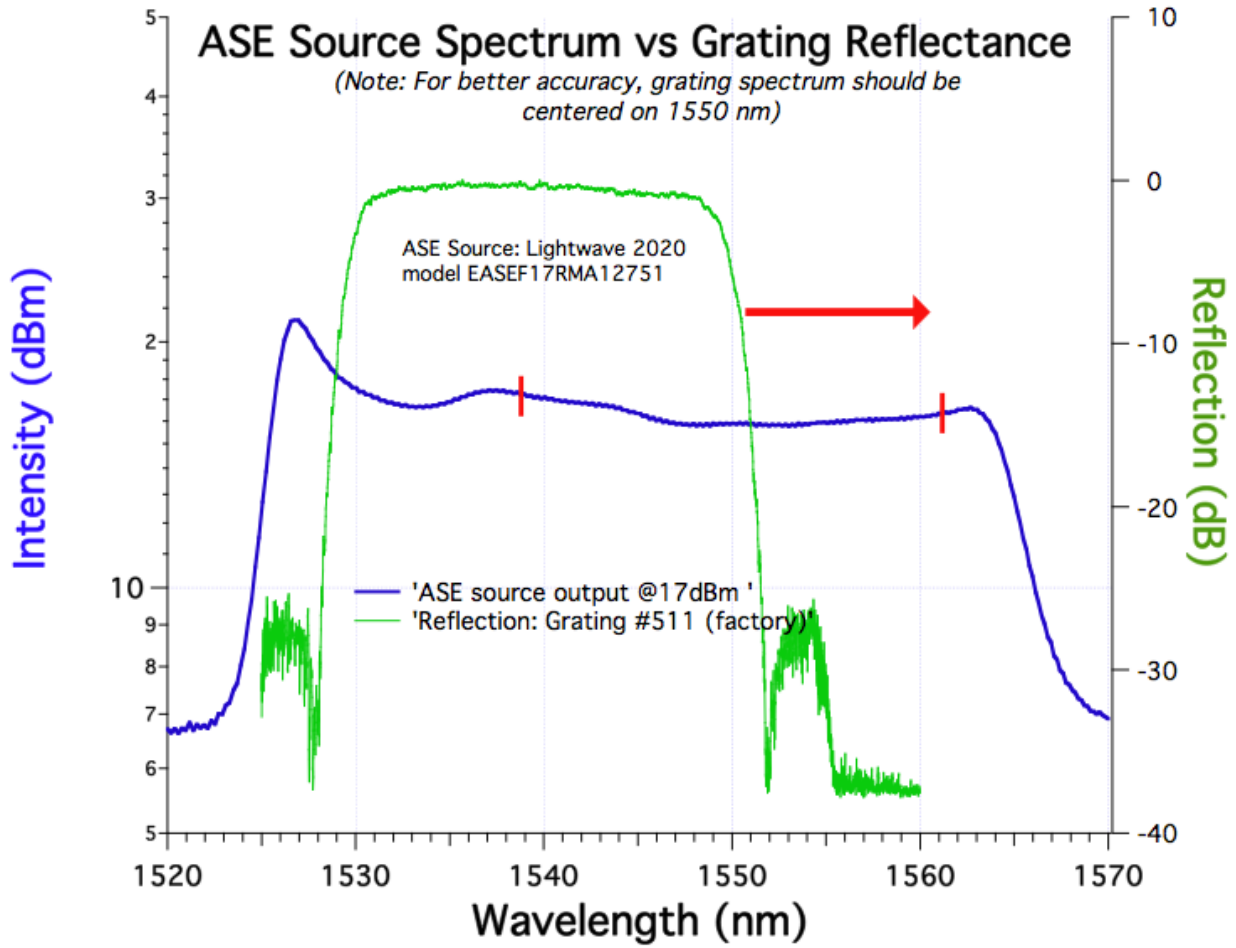
Chirped Fiber Bragg Grating



Broad band reflection



ASE Light Source and Chirped FBG



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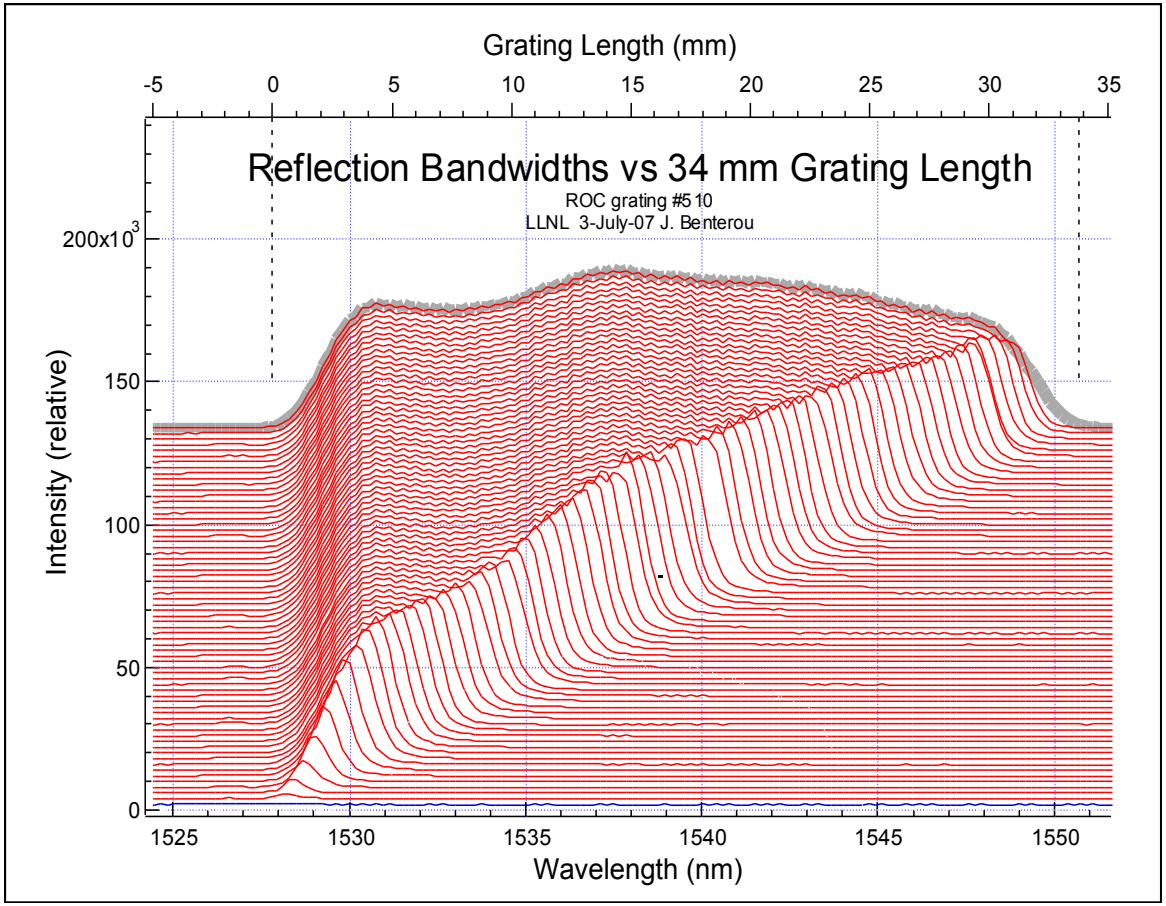
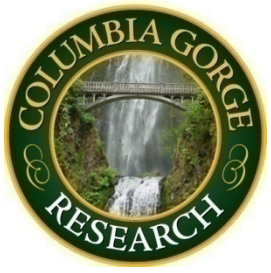
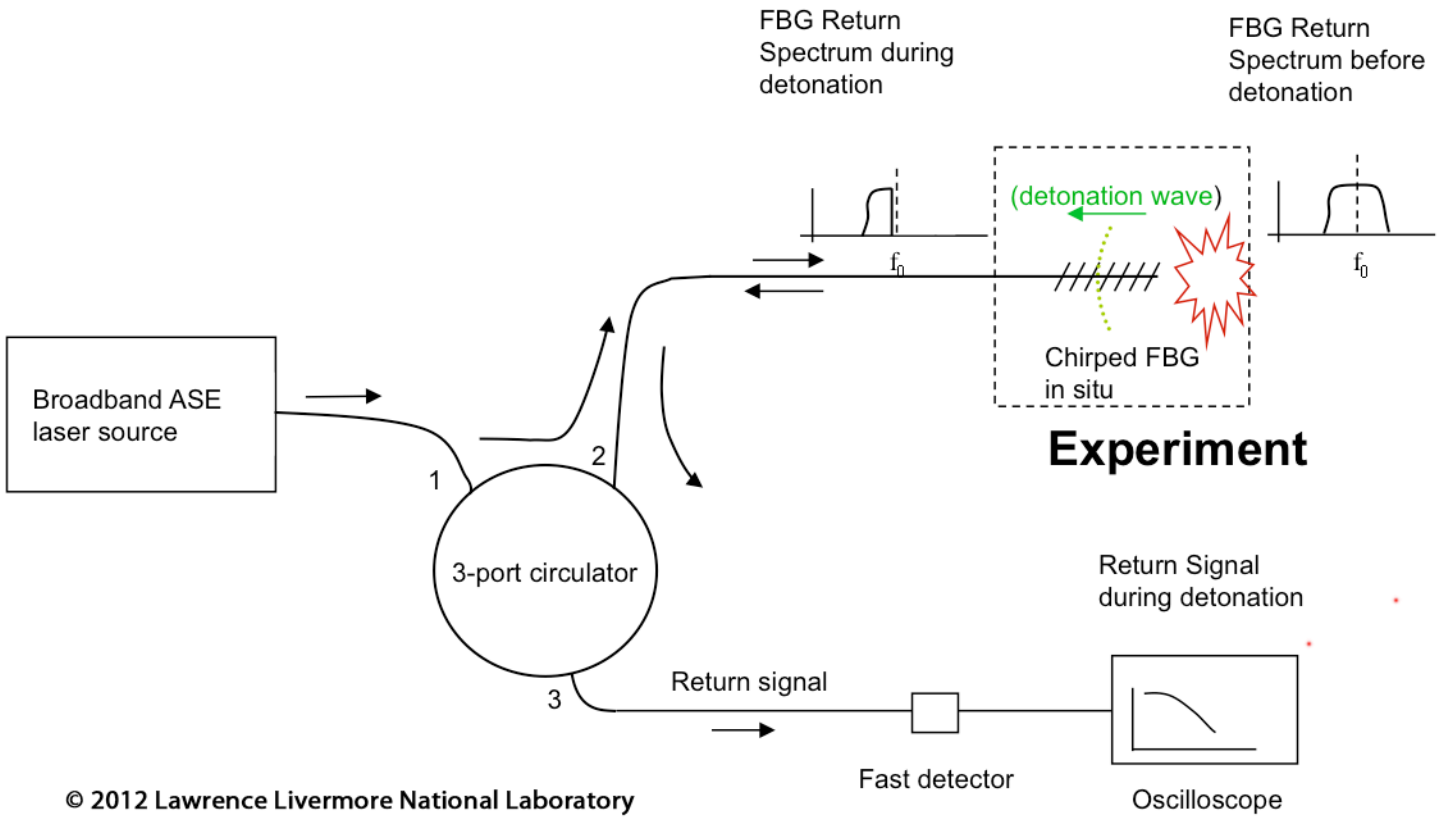
Cut Back Spectral Profiles





Simplified Test Layout

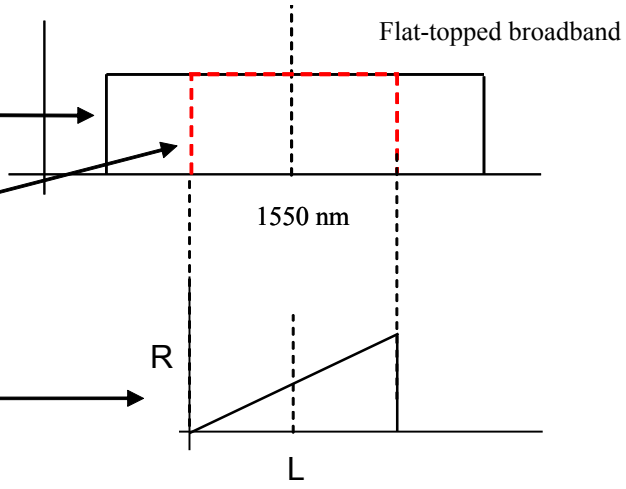


Basic Operation Velocity, Position

ASE Broadband
Laser Source Spectrum

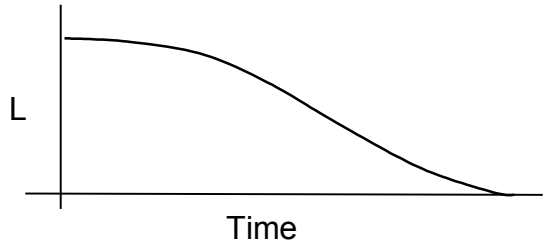
Chirped FBG Sensor Spectrum

Reflection vs FBG Length



ANALYSIS:

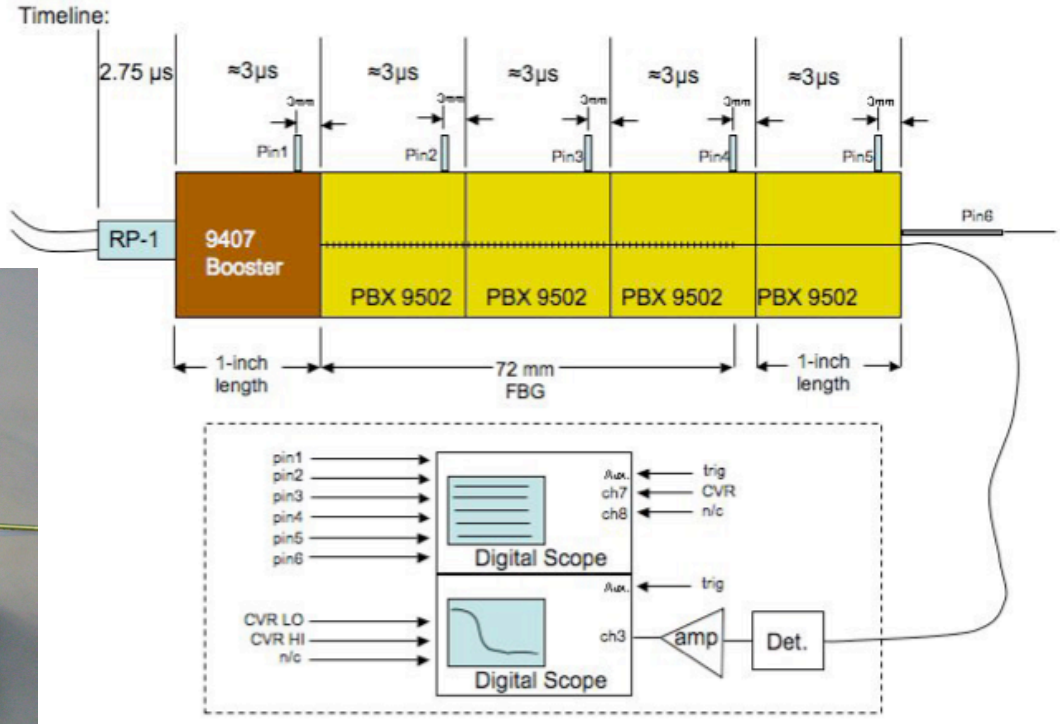
Burn Back Front vs Time



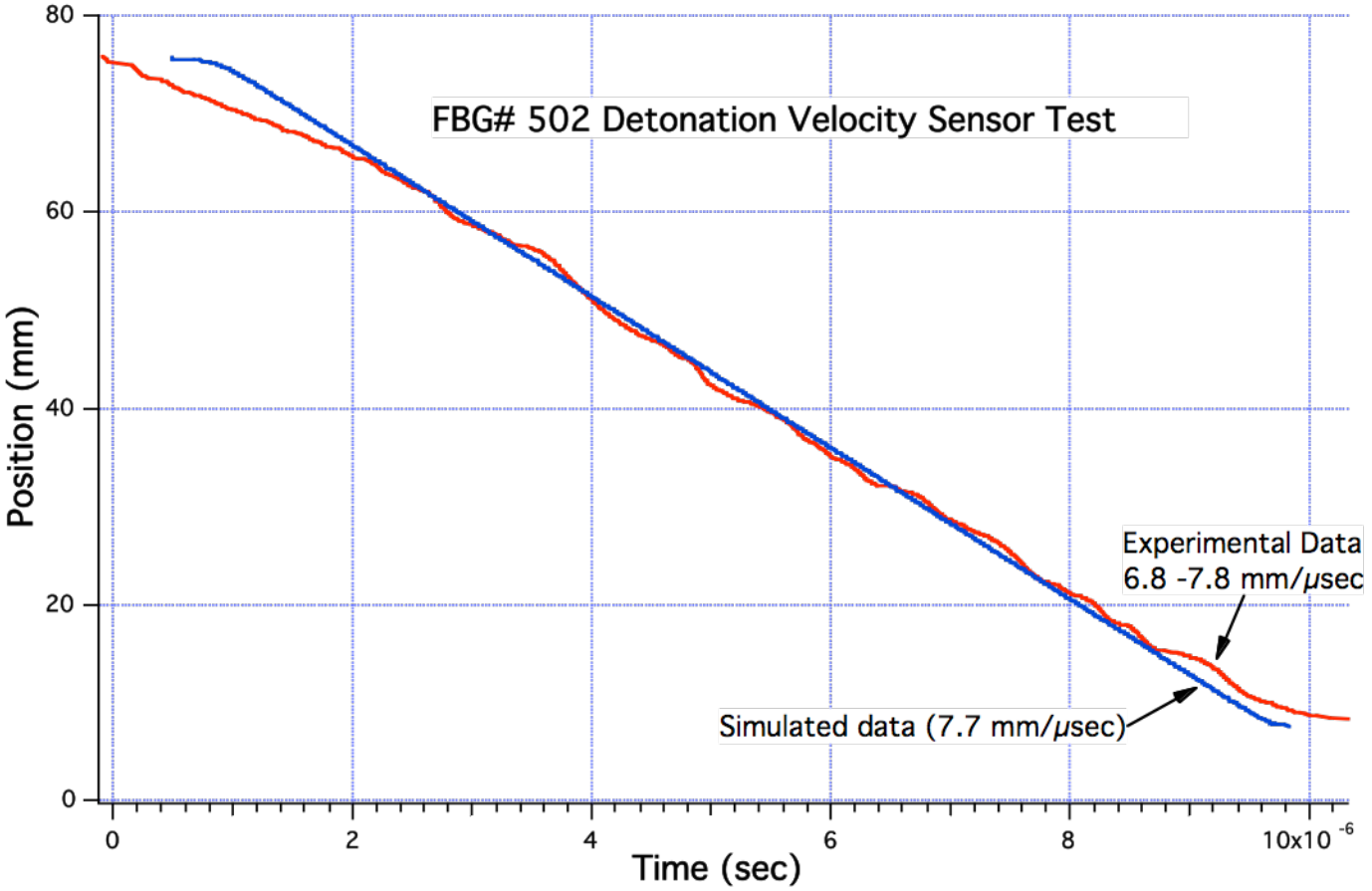
New PBX-9502 Test

Experimental Setup:

Experimental Setup:
fiber-optic Bragg grating detonation velocity sensor



PBX-9502 Test



Experimental results agree with numerical simulation in the center portion of the grating.

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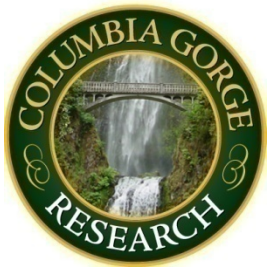
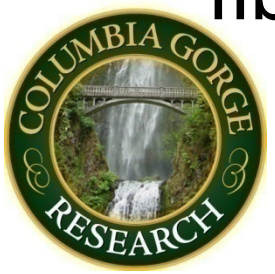
Program Objectives

- High speed system for pressure, temperature, velocity and position during burn, deflagration and detonation
- Incorporate system into appropriate test bed
- Demonstrate effectiveness of approach
- Evaluate Results

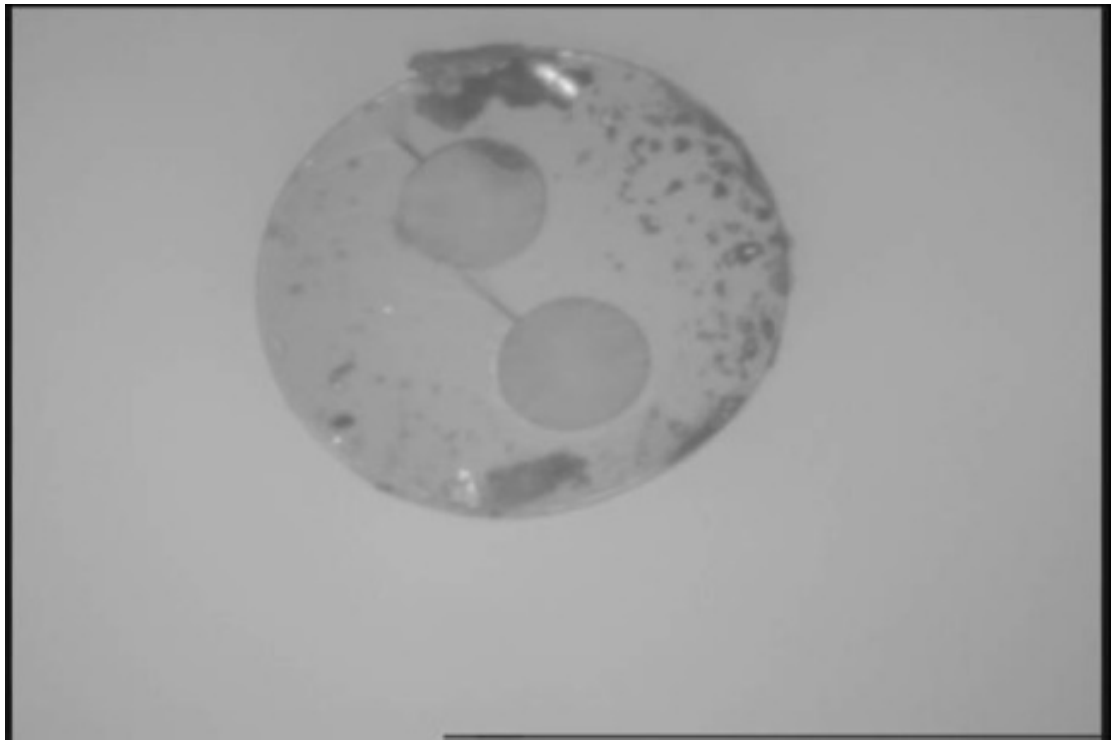


New Sensor Types

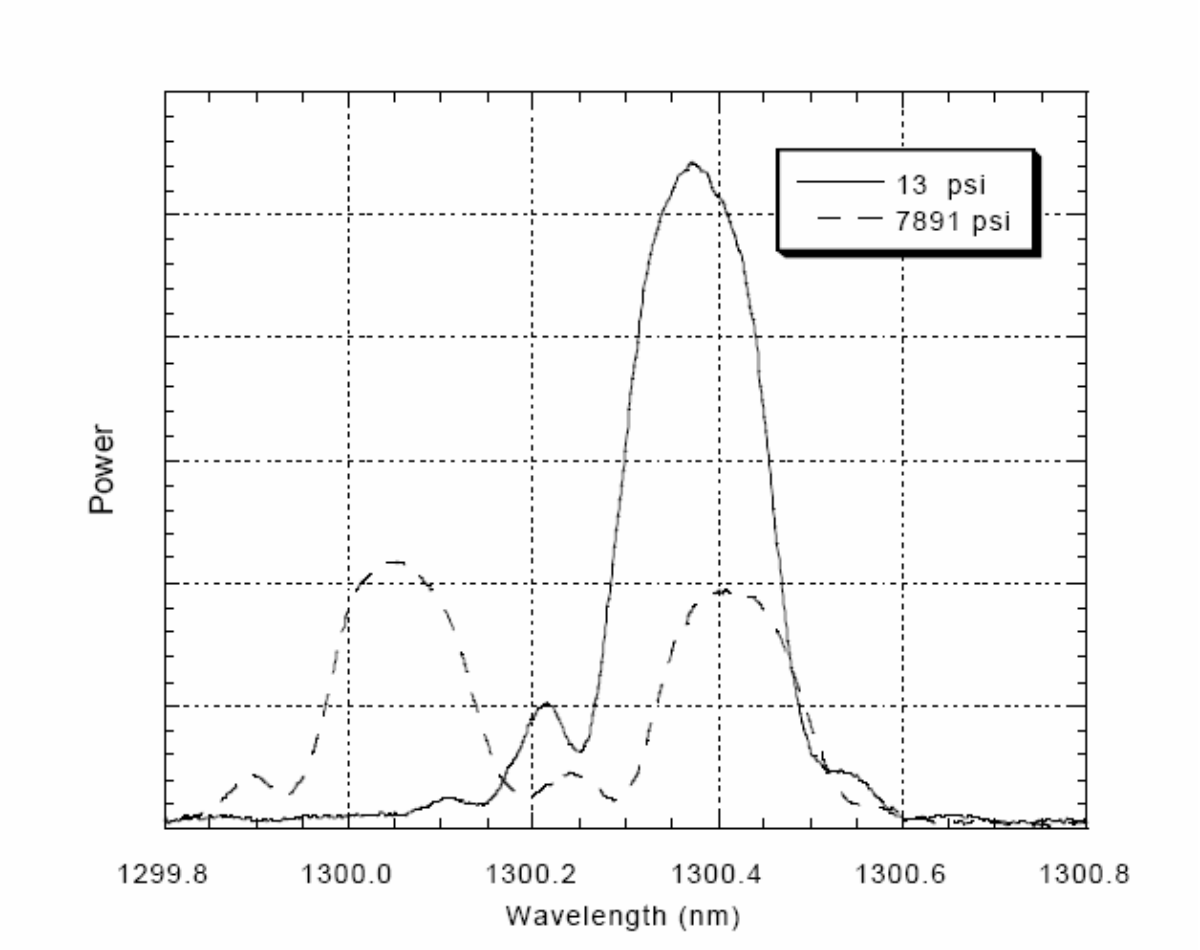
- (1) A chirped fiber grating with “masked” regions to allow position measurement and investigate pressure/temperature shifts 135 mm in length
- (2) Uniform 6 mm long fiber gratings written into side-hole optical fiber (second approach to objective of first time high speed pressure measurement, 1000 C fiber gratings)



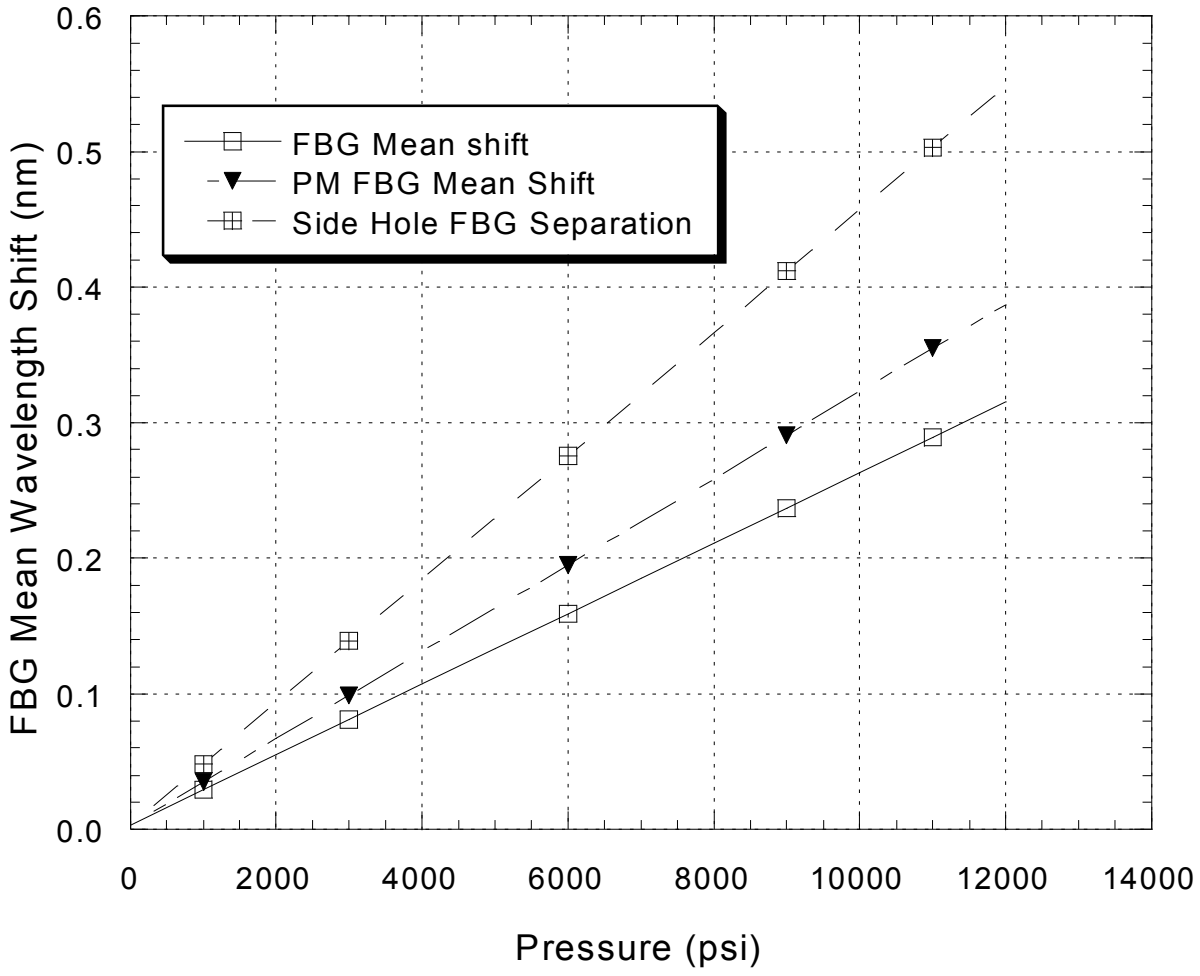
Side-hole Optical Fiber



Side-hole Optical Fiber (2)



Conventional, PM and Side Hole Fiber Response to 12000 psi



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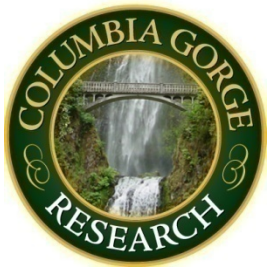
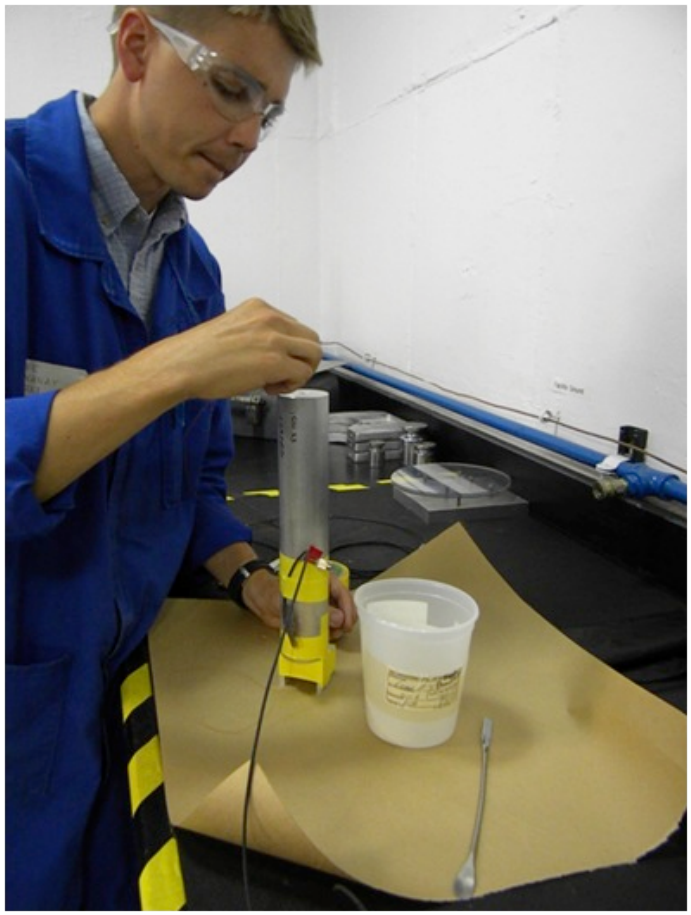
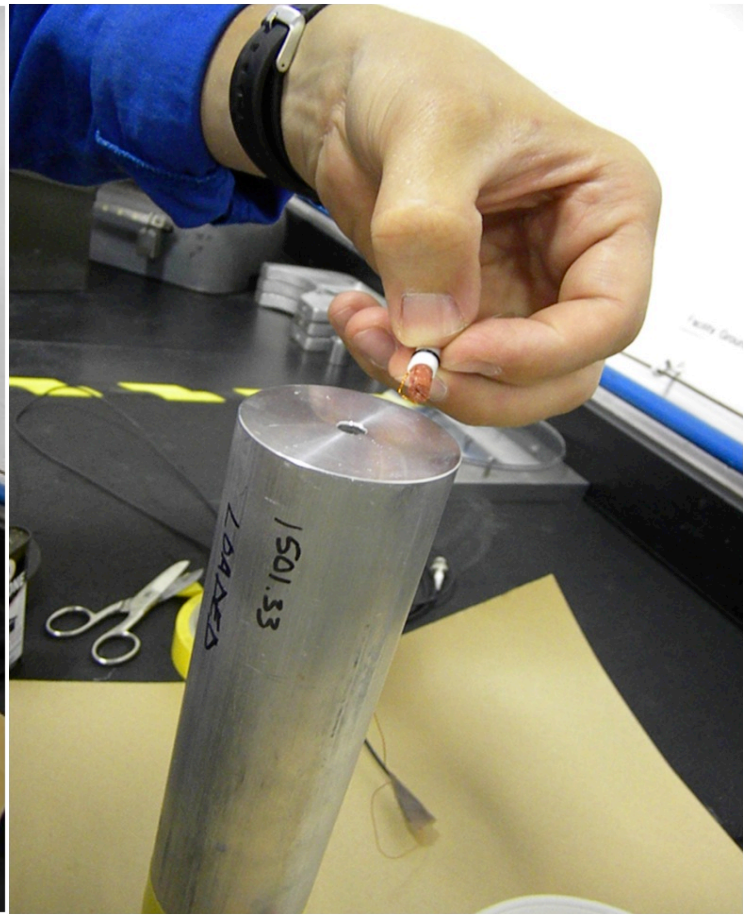
Demonstration Articles

- Three approaches were considered, propellant “test bomb”, autoclave and Russian DDT
- Russian DDT was selected because (1) could demonstrate burn, deflagration and detonation, (2) cost effectiveness allowing more test runs, (3) best media for pressure demonstration



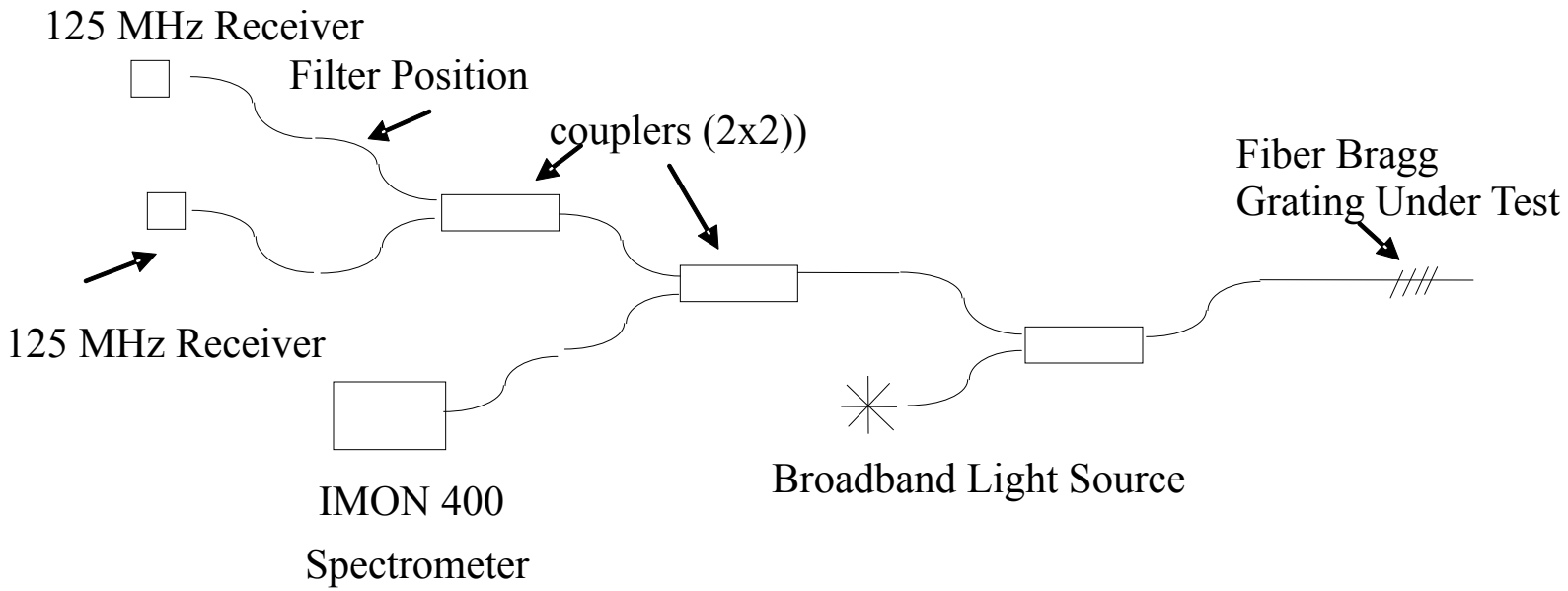
Preparation of Test Articles (2)





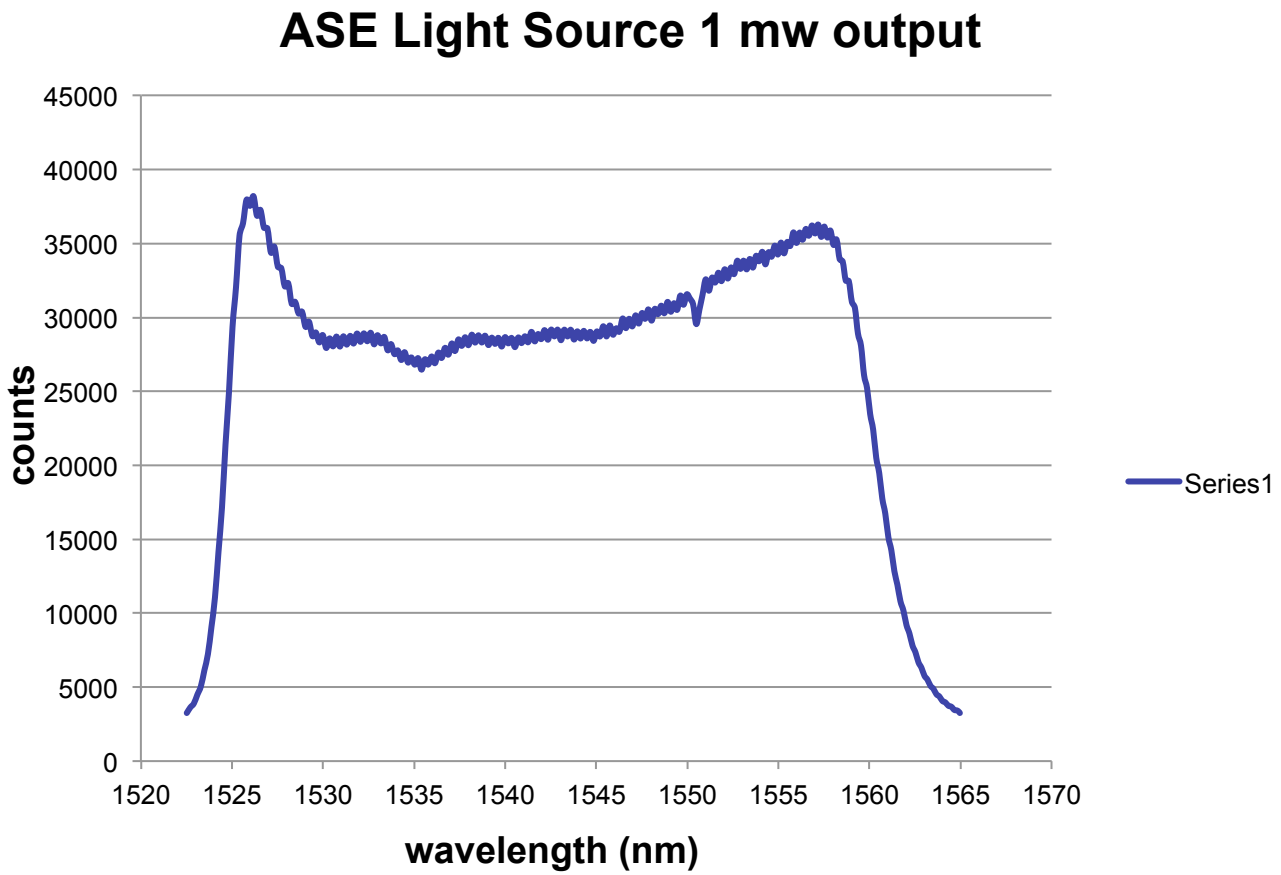
Placement in Test Fixture

Block Diagram of Test Layout



Expanded System for dual lines and/or high speed acquisition

Spectral Profile of ASE Light Source



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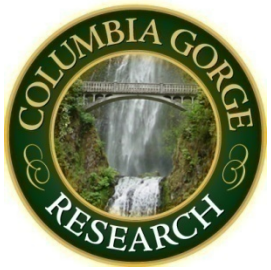
Spectral Profile of ASE Light Source

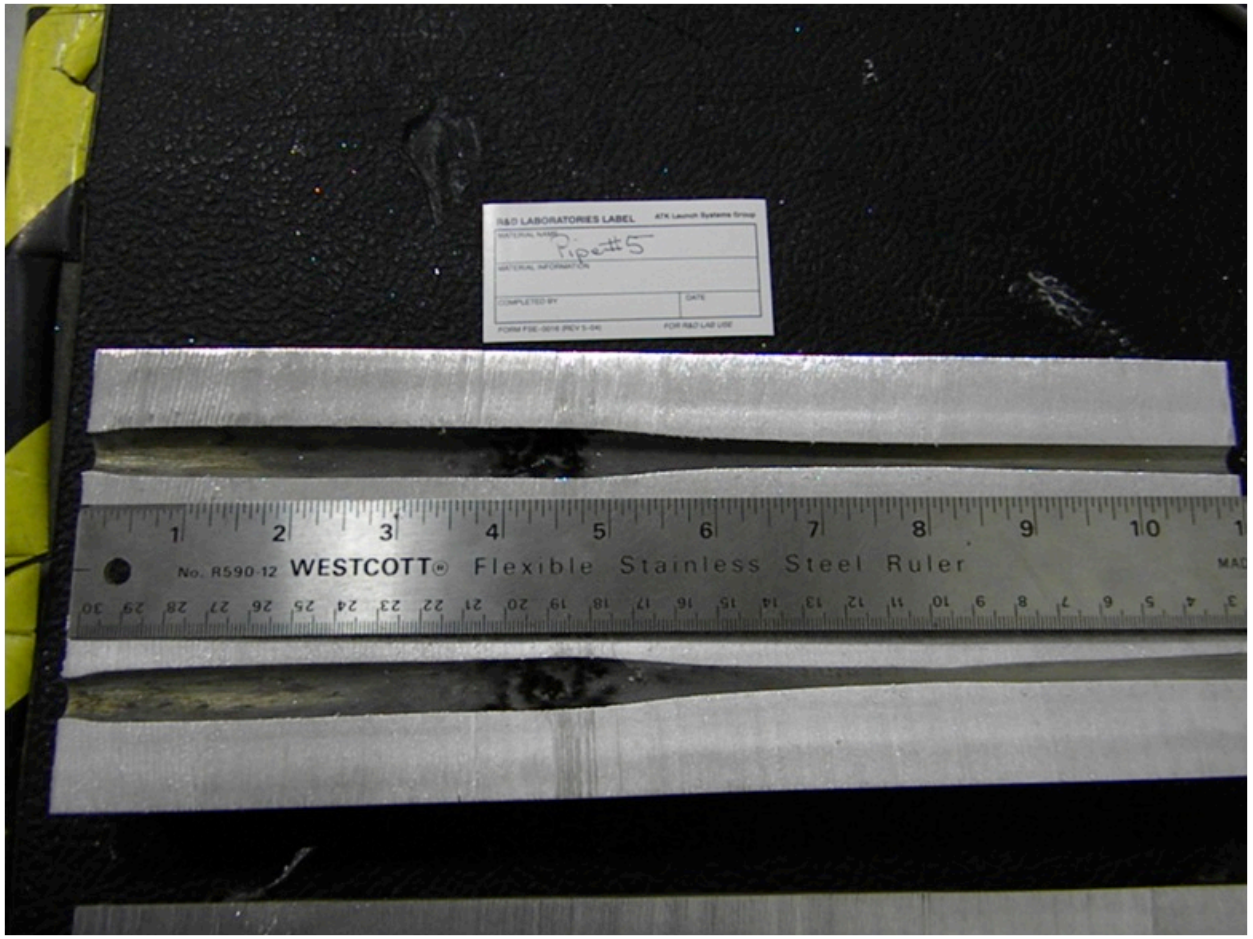
- Spectral region at about 1528 nm is at 38000 counts adjacent to 28000 count region
- Rapid fall off in response at shorter wavelengths
- Width of peak about 5 nm

Spectral Profile of ASE Light Source (2)

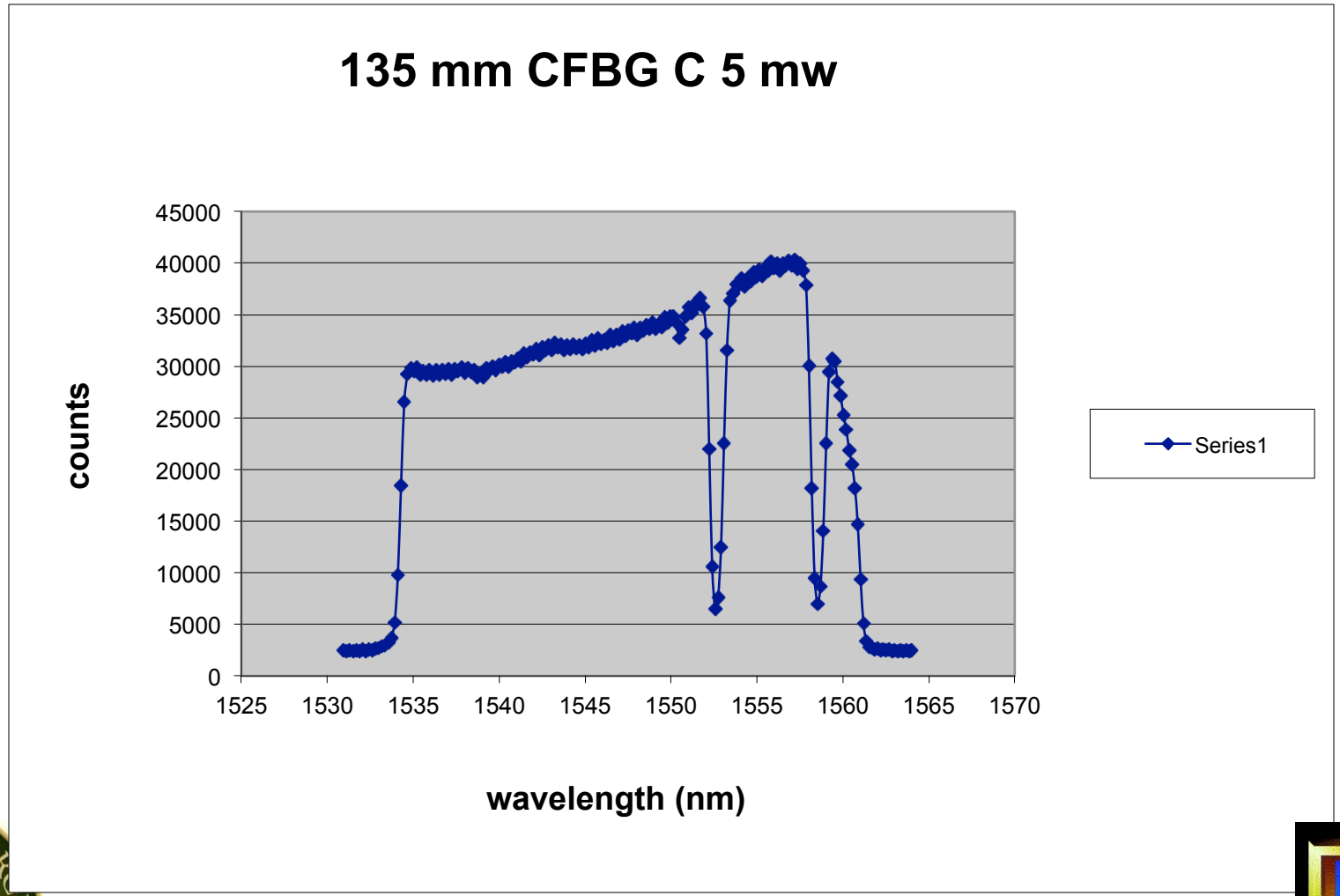
- When pressure is first applied the fiber grating will move toward shorter wavelengths…toward lower light emission levels (signal will drop… followed by peak when 1528 peak is encountered)



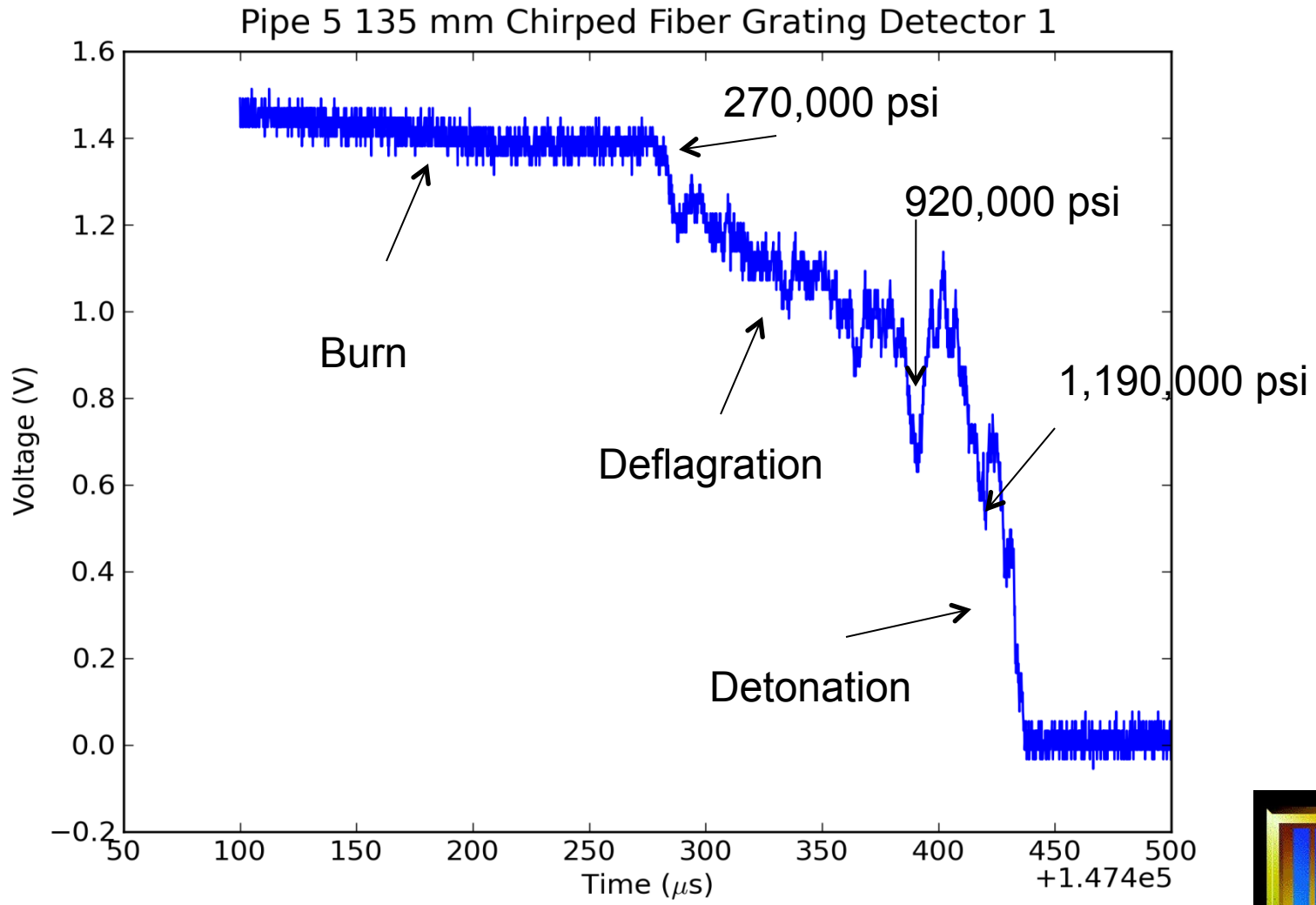
Pipe 5


R&D LABORATORIES LABEL
Pipe#5
No. R590-12 WESTCOTT Flexible Stainless Steel Ruler

Pipe 5 135 mm CFBG Spectra



Pipe 5 135 mm CFBG Det 1



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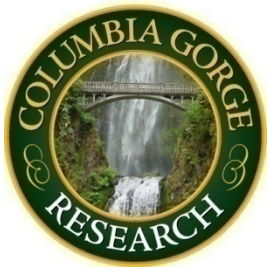
135 mm CFBG Sequence of Events

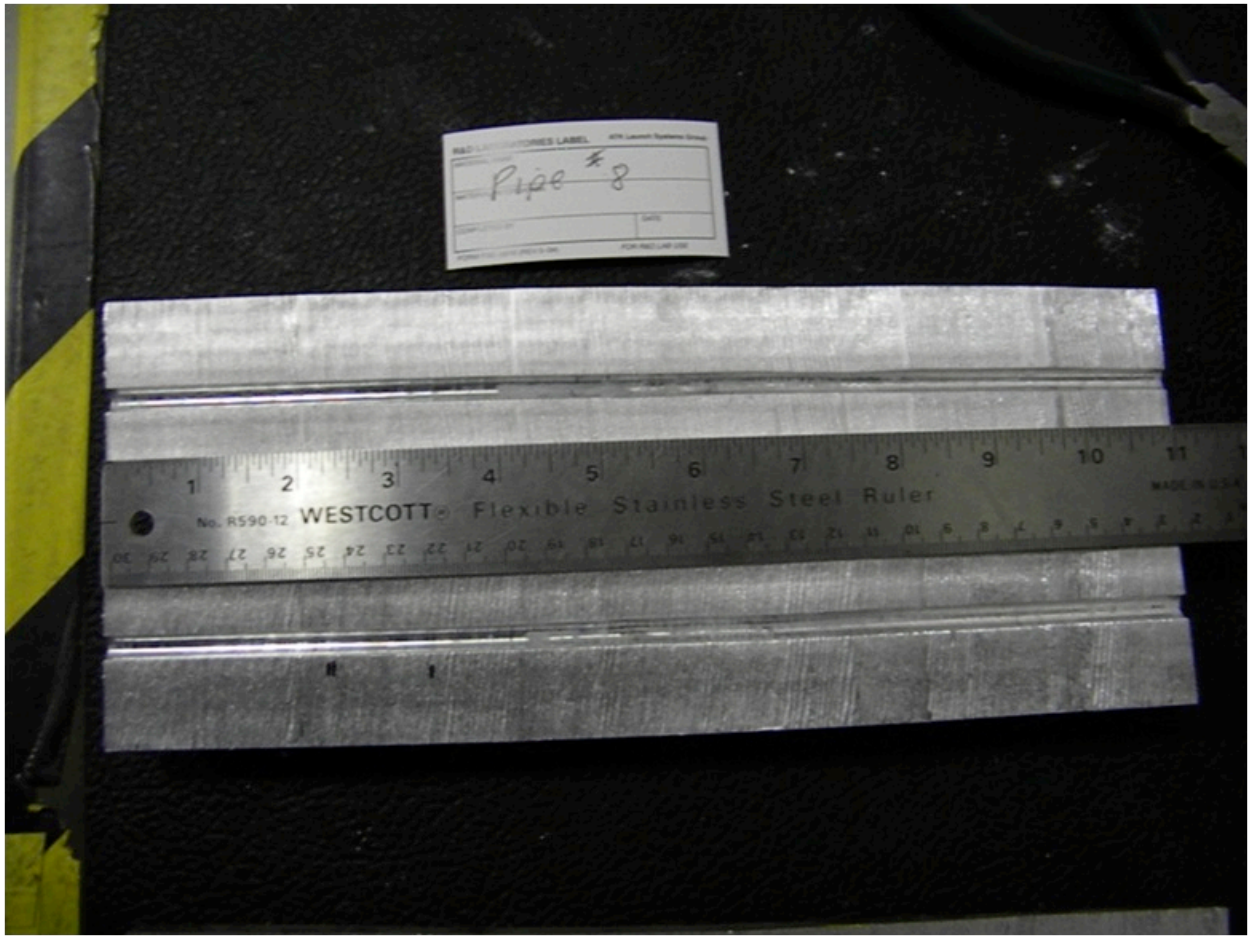
- Spectral edge spans form 1535 to 1562 nm
- For this type of fiber a 10,000 psi pressure results in a shift of about 0.26 nm
- During “burn” there is a slow pressure rise sufficient to drive 1535 edge beyond 1528 nm (270,000 psi) (note steady decrease in amplitude as profile moves across ASE profile)



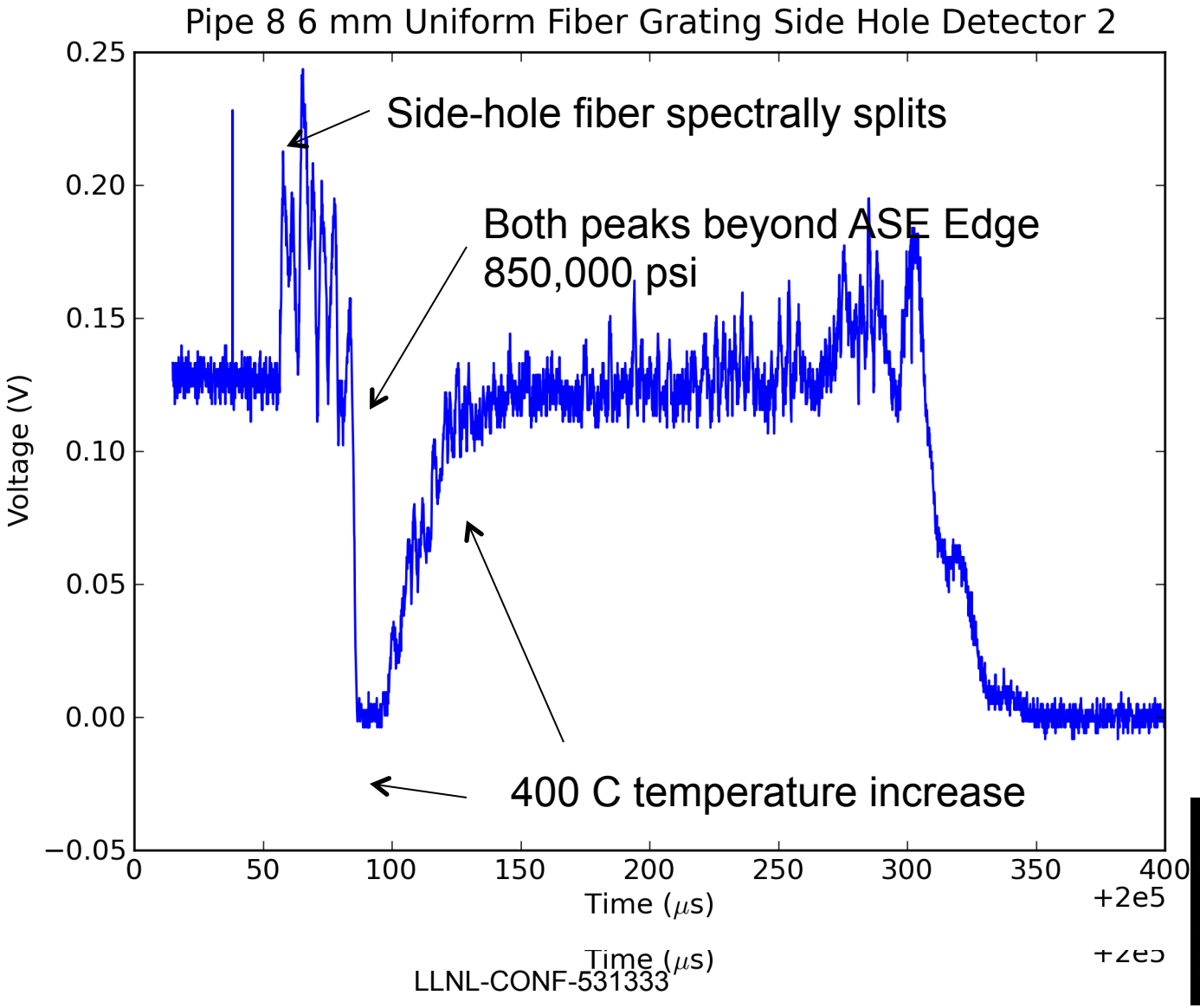
135 mm CFBG Sequence of Events (continued)

- During deflagration first “dip” marker at 1552 is driven off the edge 24 nm shift or 920,000 psi
- Second dip near transition from deflagration to detonation occurs at 1559 nm 31 nm shift or 1,190,000 psi
- Complete transition to detonation at 1560 nm or about 32 nm shift or 1,230,000 psi

Pipe 8



Pipe 8 6 mm uniform FBG side hole on det 2



Time (μs)
+2e5

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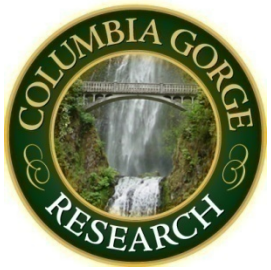
Pipe 8 6 mm uniform FBG side hole on det 2

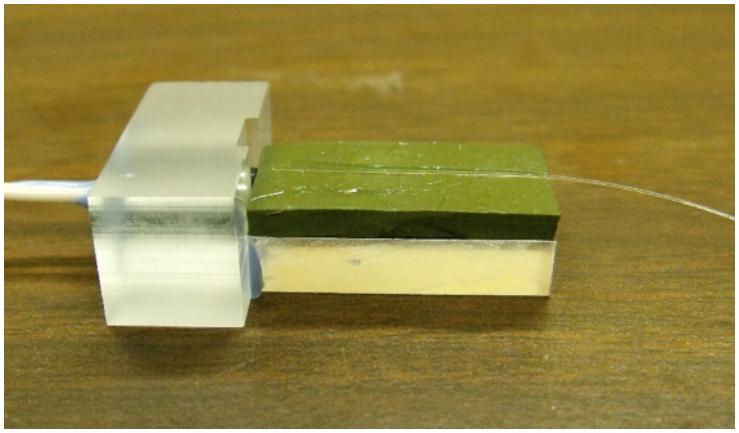
- No blocking filter
- First peak driven over ASE peak, followed by second peak being driven over and return to nominal level
- Steady then first peak reaches ASE peak, then consumption of FBG or forced over ASE edge by pressure

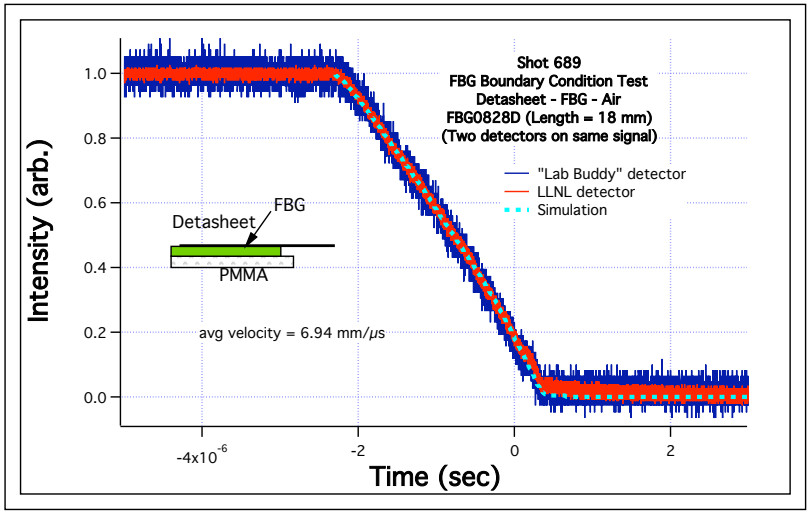


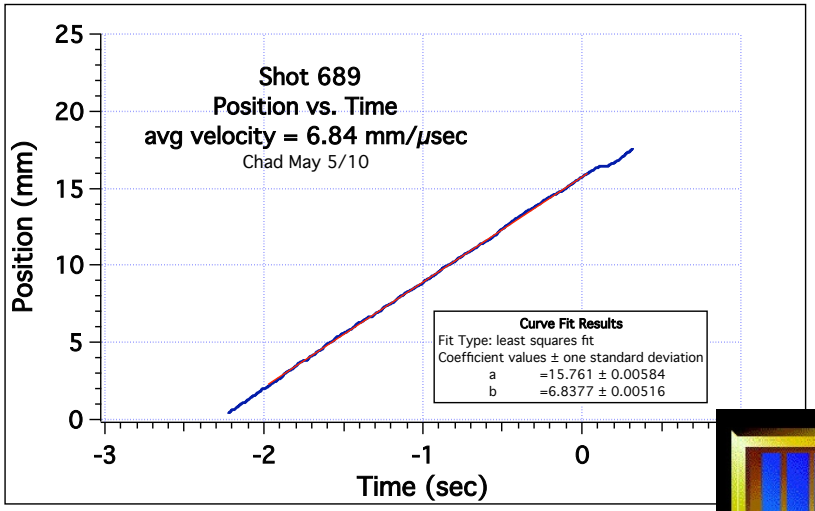
Read Out Unit Packaging

8 channel systems are in place at LLNL and LANL

Surface Placement Results



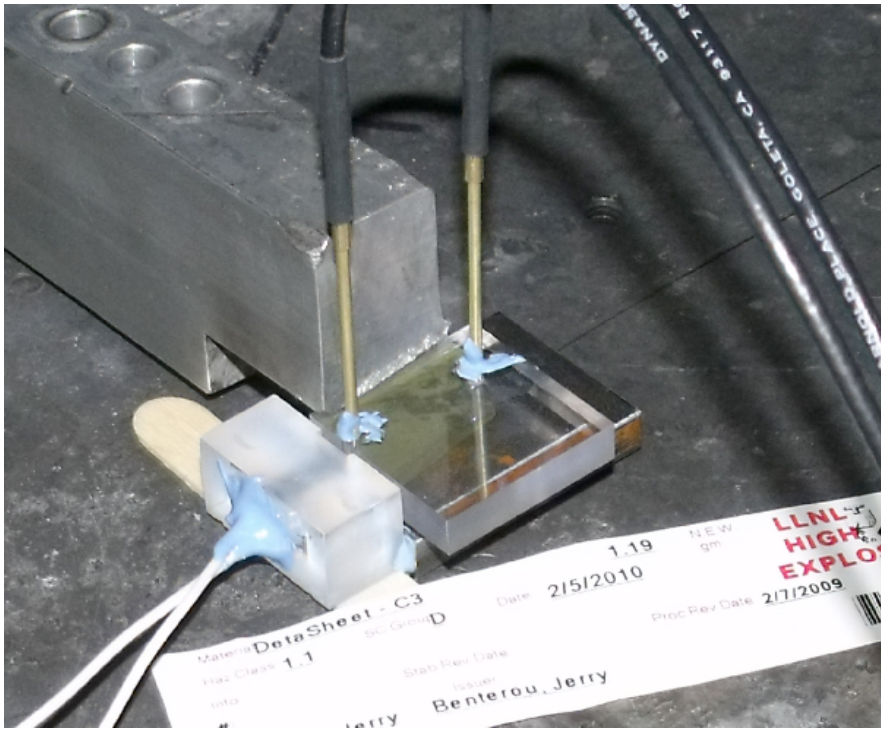


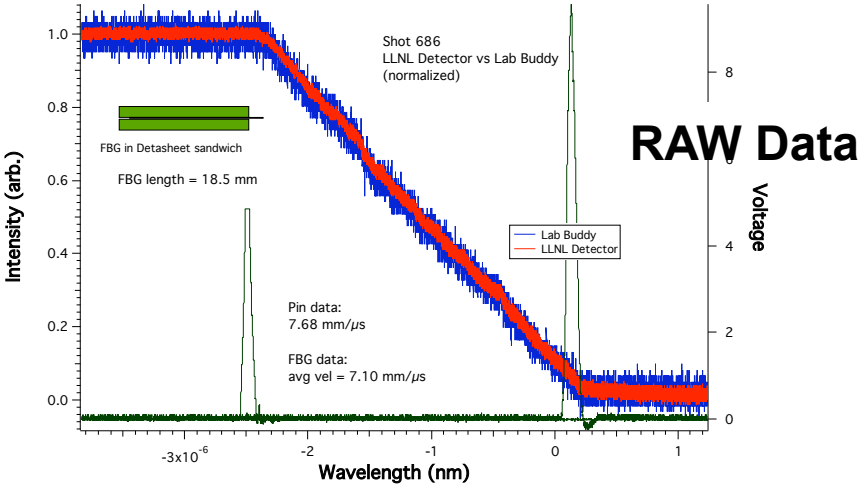


The CFBG detonation velocity sensor can track the progress of a detonation along a surface.

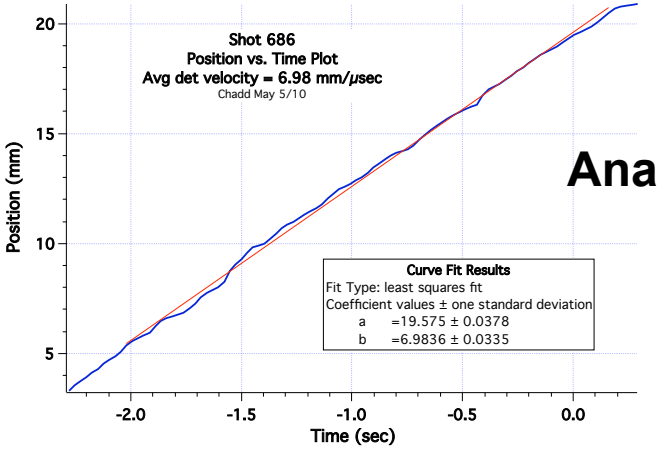
Between HE Layers

Boundary Condition: Embedded (HE / HE)





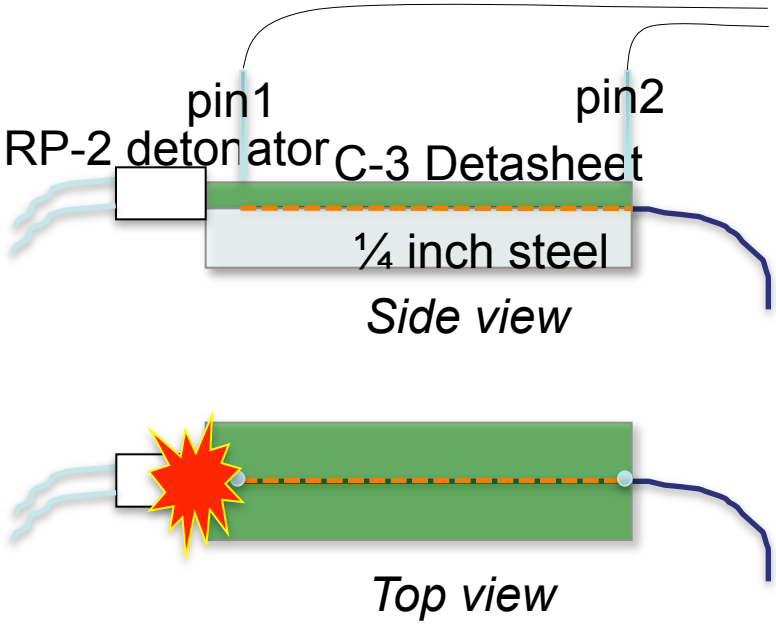
RAW Data

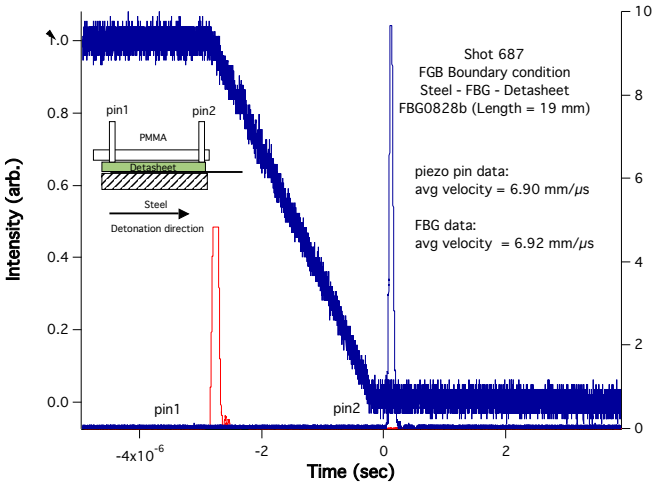


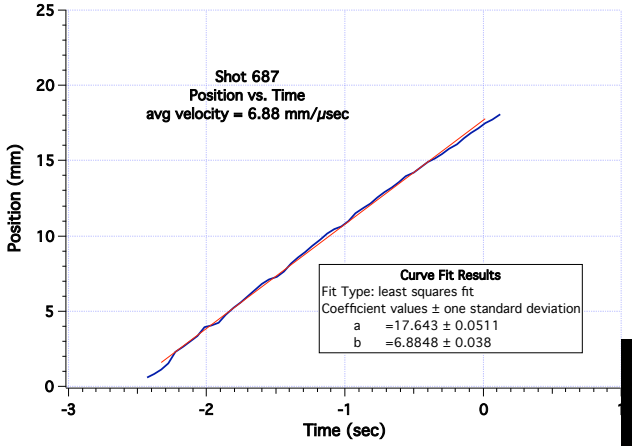
Analyzed Data

Steel HE Boundary

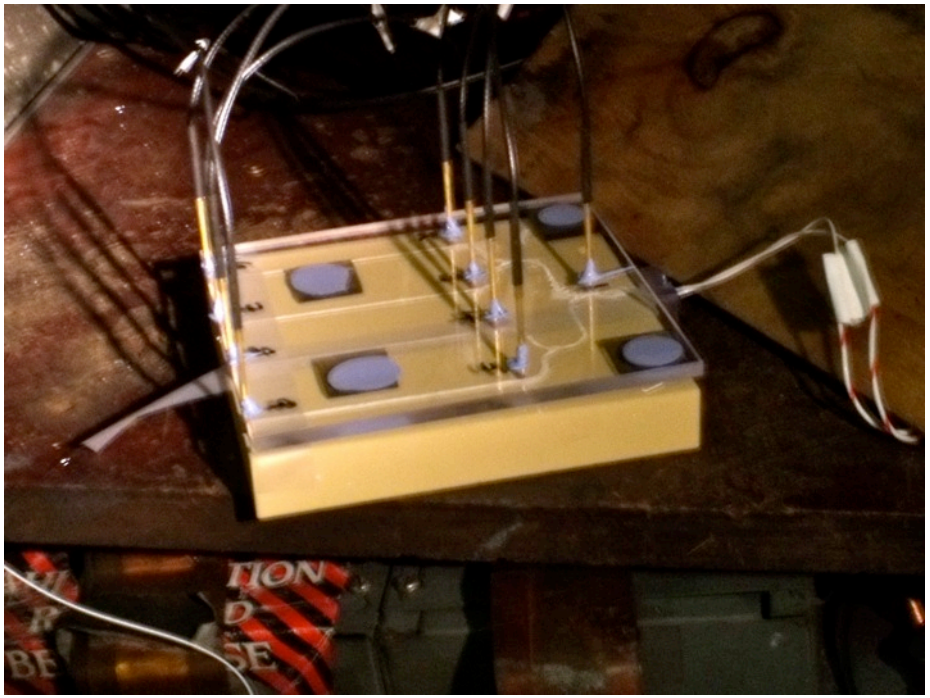
Steel-HE boundary condition



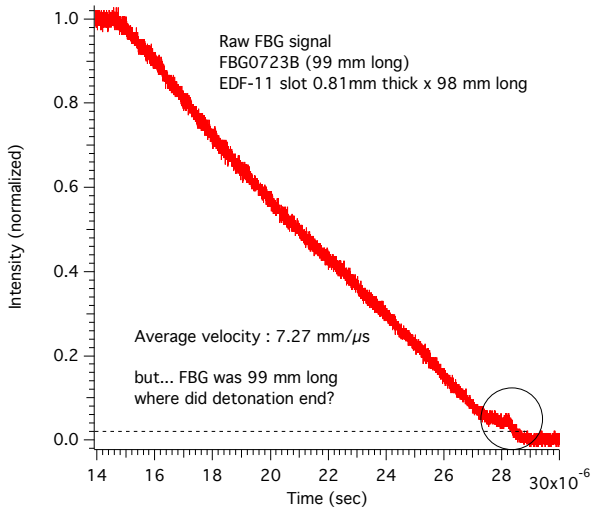


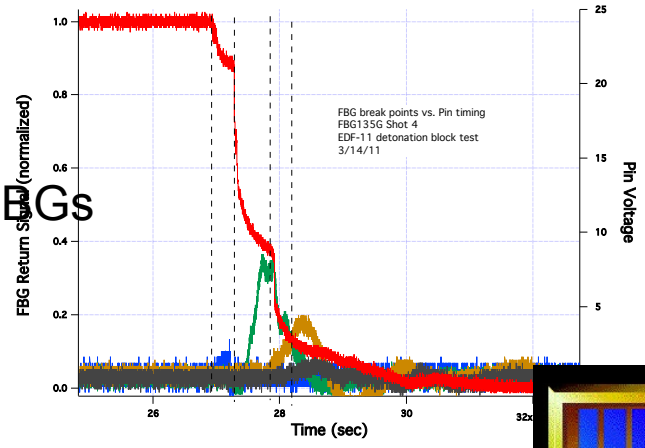


Edge Effects



Assembled EDF-11 test-shot with pins and CFBGs



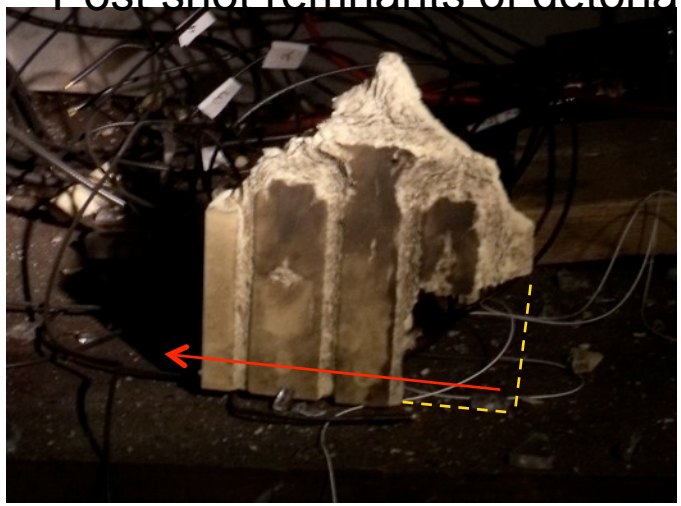


Post-shot timing data shows good correlation between pins and CFBGs, But...

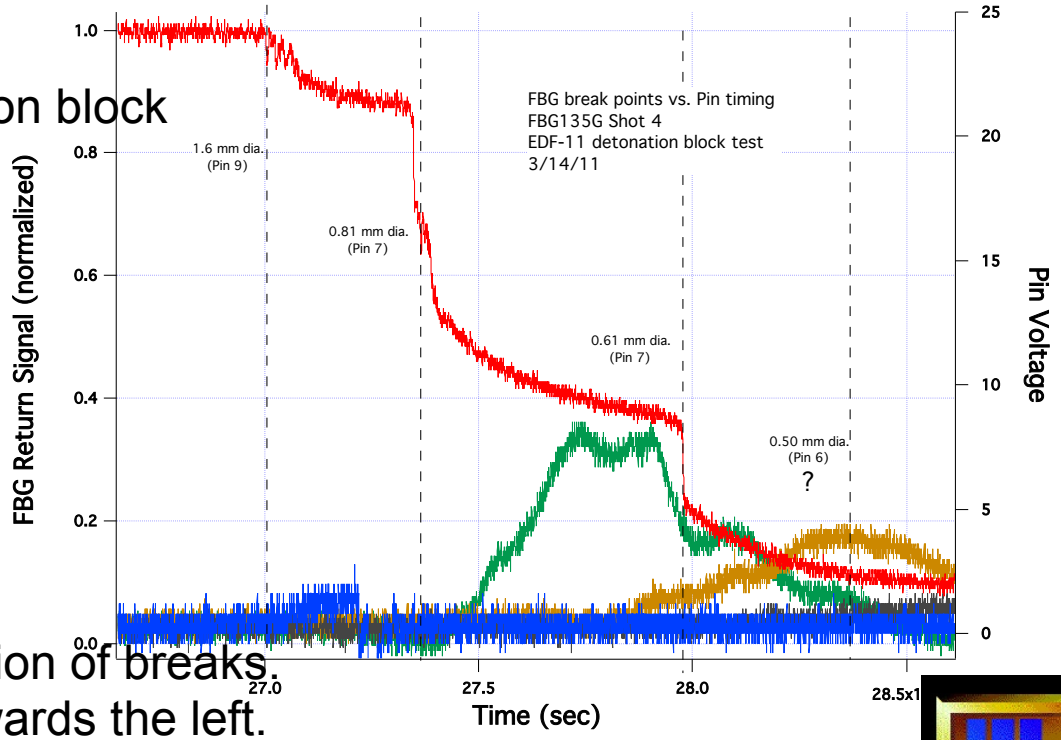
Edge Effects (2)

…weak shocks near the ends of the CFBG sensor may may be difficult to measure

Post shot remnants of detonation block

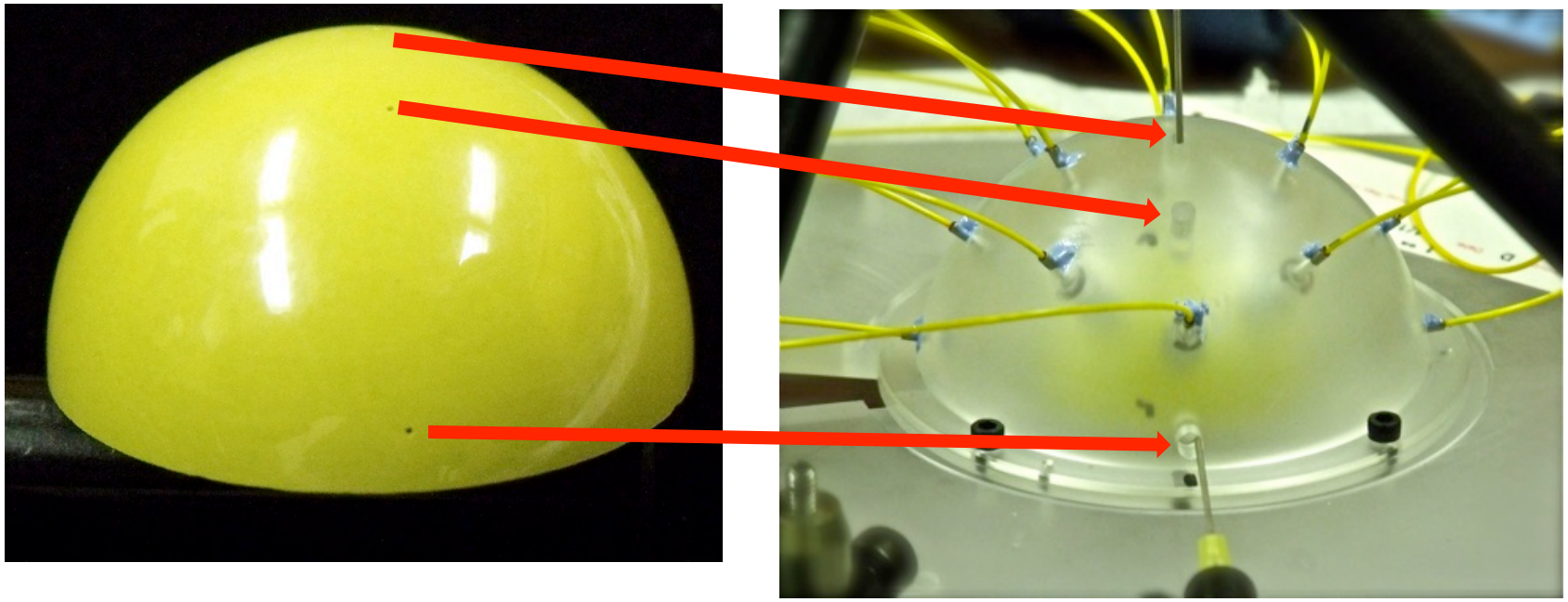


CFBG Placement showing direction of breaks. Shock become weaker going towards the left.



Measuring Blast Shape

We tried firing a uf-TATB booster with three embedded CFBG sensors



Booster with holes drilled for embedded CFBGs

Booster in test fixture with PDV probes and embedded CFBGs

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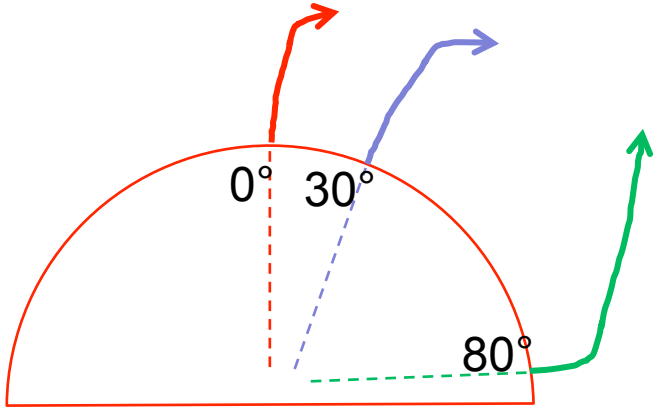
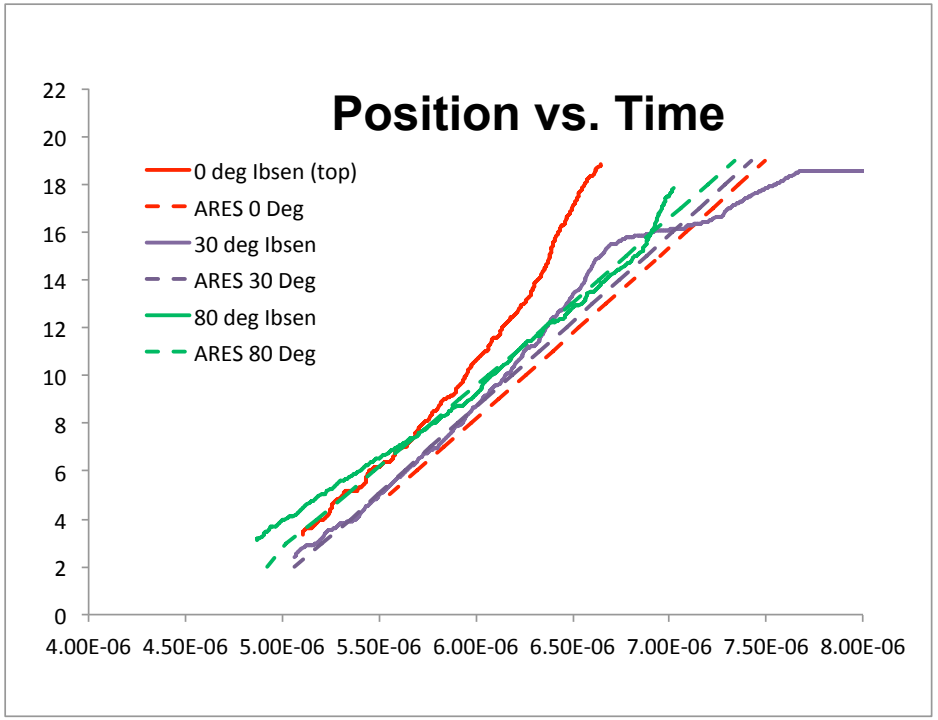
Blast wave mapping

Data was successfully acquired from 3 embedded FBG detonation velocity sensors …



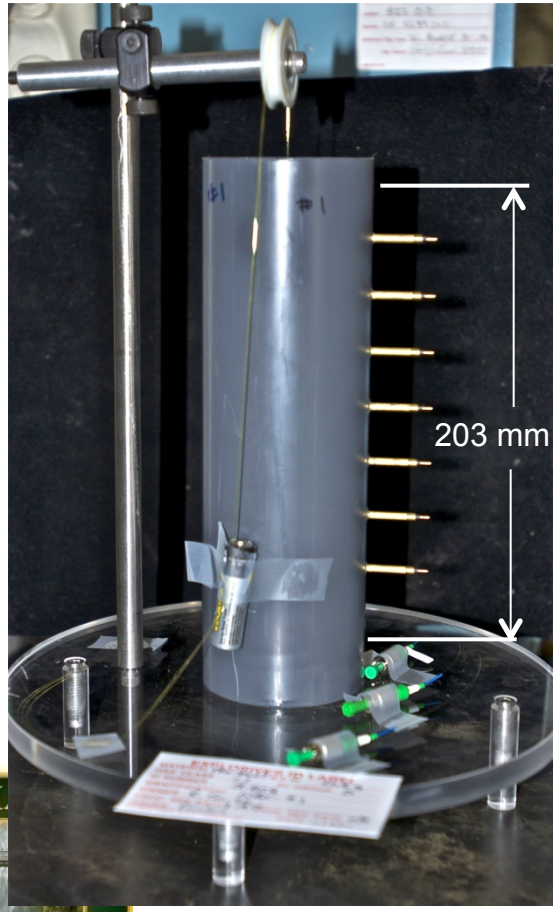
Embedded FBGs locations in booster



…analyzed return signals from FBG sensors showed that jetting was occurring (as predicted in simulations).

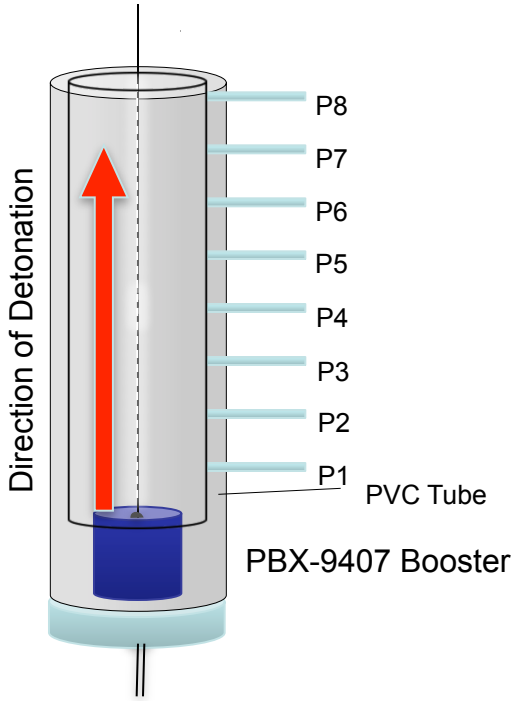
Multiphase Blast Experiments at LLNL

Recent multi-blast (MBX) experiments required us to measure detonations along longer paths (≈200 mm):



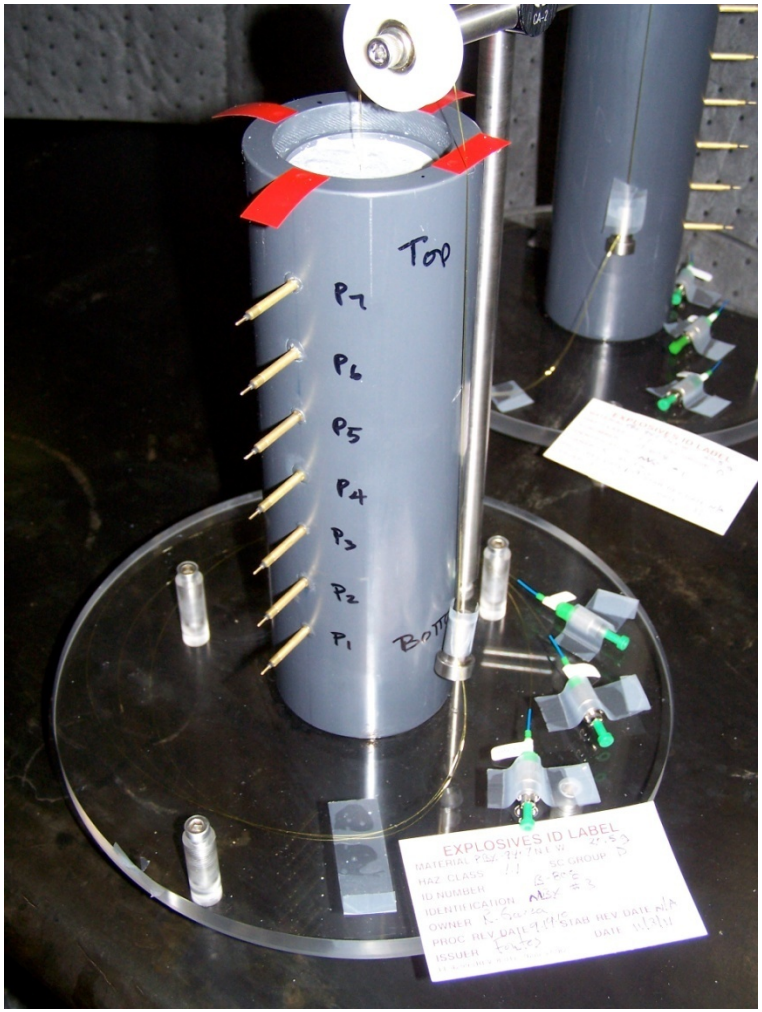
- 33 % LX-20 / 67% metal powder (by weight) were mixed and poured into a 2” x 8” mold.
- 3 concatenated FBGs were embedded into the explosive charge

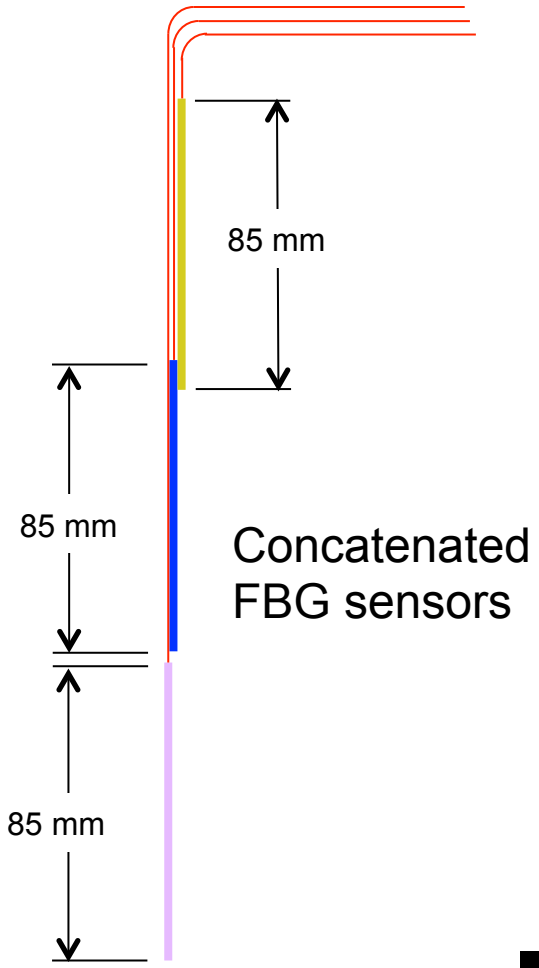
The FBG detonation velocity diagnostic was used in a multiphase blast experiment at LLNL in 2011



LLNL-CONF-531333

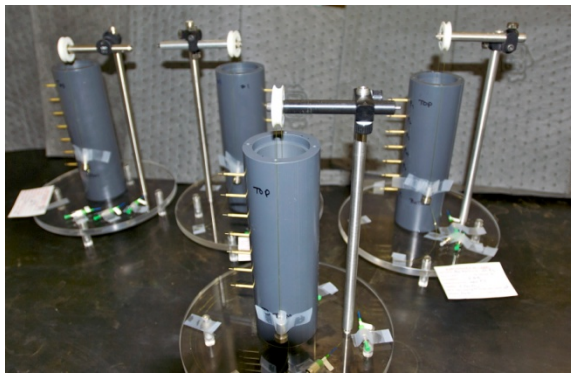
Multiphase Blast Experiments at LLNL



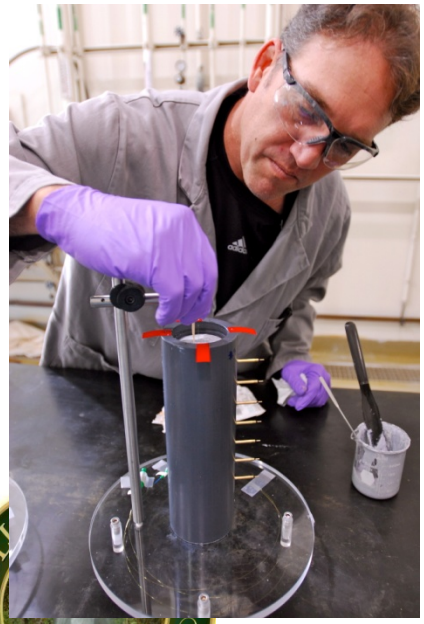


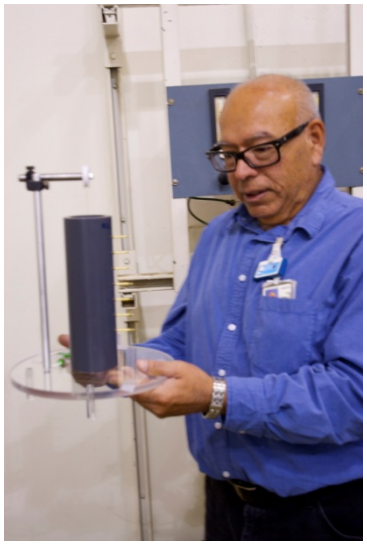
Concatenated FBG sensors

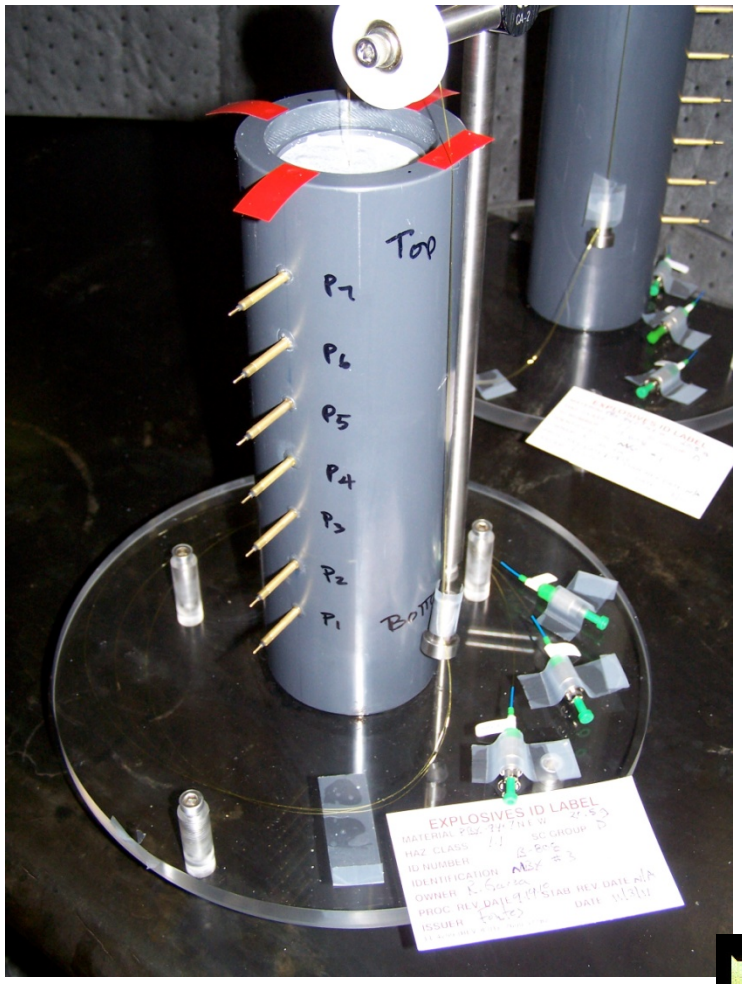
Multiphase Blast Experiments at LLNL



MBX shots assembled



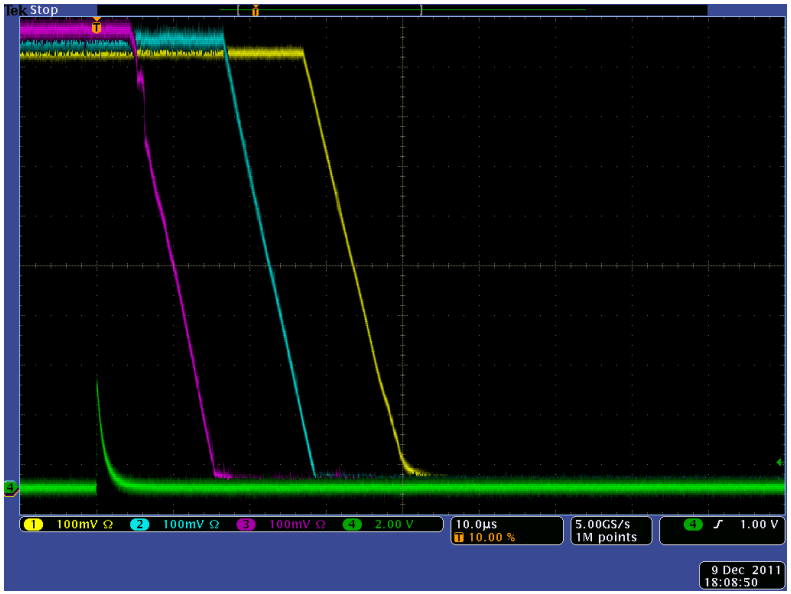




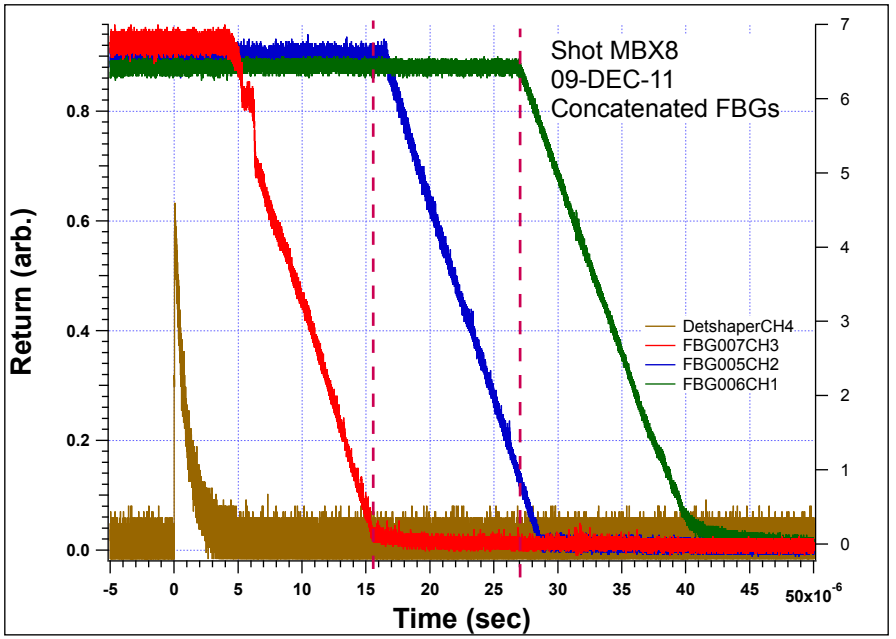
Chirped FBG detonation velocity sensors were cast into explosive

Multiphase Blast Experiments at LLNL

Raw FBG data are digitized for analysis



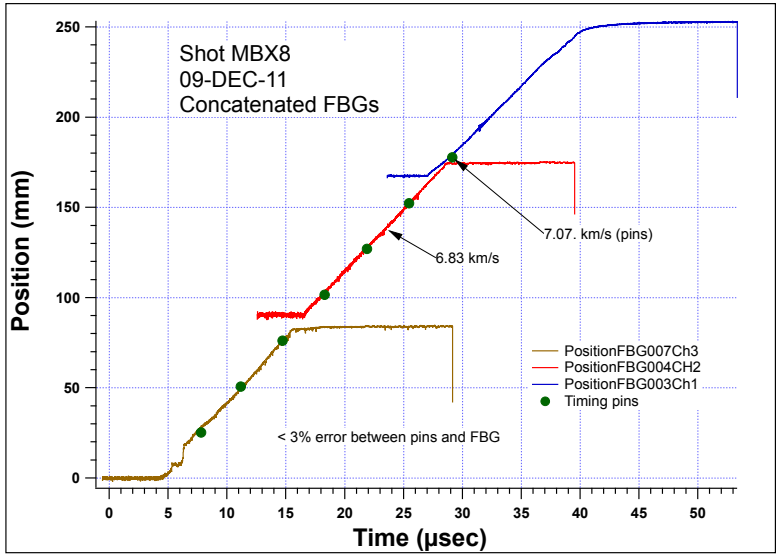
Screen capture from Scope

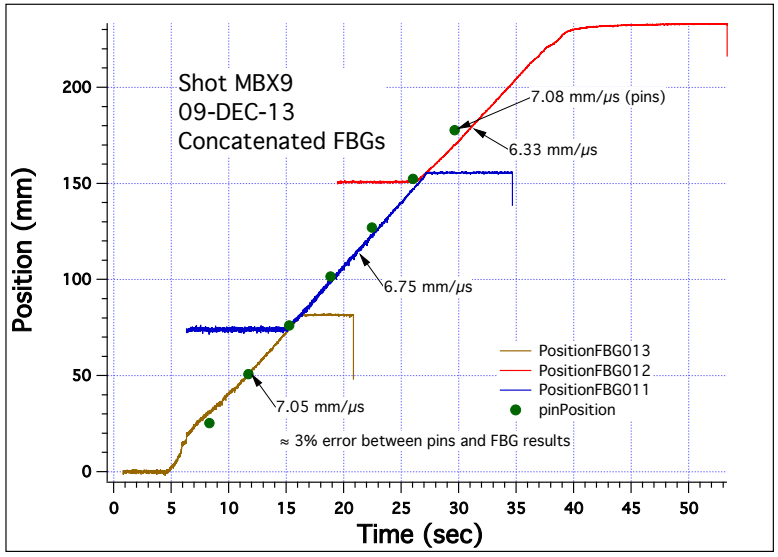


Digitized signals plotted in IGOR

Multiphase Blast Experiments at LLNL

Position vs. time plots reconstructed from raw scope data

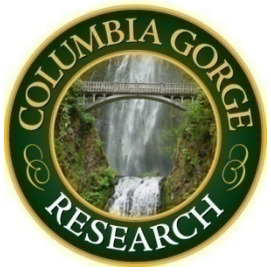




Results of two shots show pins and FBG sensor outputs agreed within approx. 3%. We think the error is likely due to the different locations of the pins and FBG sensors.

Summary

- A new diagnostic tool that can be used to support measurement of velocity, position, pressure and temperature during burn, deflagration and detonation has been demonstrated
- Early adopters are already beginning to show the technology is cost effective and offers measurements not previously available



Acknowledgements

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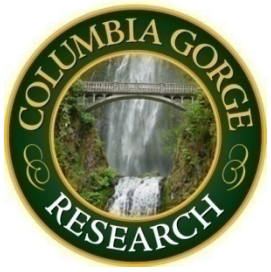
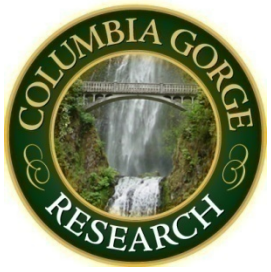
- Early side hole fiber pressure sensor work was done with Schlumberger Doll Research and technical support of Robert Schroeder



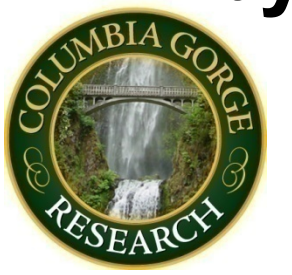
Acknowledgements (2)

- CGR work was performed under Army SBIR contracts W31P4Q-10-C-0187 and W31P4Q-11-C-0209
- The help of our technical program monitors William Chew, Stan Smith and Jessica Stanfield and Dawn Gratz of the Army SBIR office has been invaluable and we would like to offer our sincere thanks.



Acknowledgements (3)

- **The work by Lawrence Livermore National Laboratory was performed under the auspices of the U.S. Department of Energy under Contract DE-AC52-07NA27344. This work was funded by the Joint DoD/DOE Munitions Technology Development Program, with matching funds provided by DOE/NNSA.**



Acknowledgements (4)

- Stephen J. Mihailov and Ping Lu of the Communcation Research Center in Canada have supplied many of the fiber gratings associated with this work, and their help is gratefully acknowledged